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ABSTRACT

This guide is intended as an aid to educators who conduct programs and activities on climate and global change issues for a variety of audiences. The selected set of currently available materials are appropriate for both formal and informal programs in environmental education and can help frame and clarify some of the key issues associated with changes in the global environment. Sections in the guide are as follows: natural climate variability, greenhouse effect, sea-level rise, ozone depletion, ecosystem response, and decision-making under scientific uncertainty, and an extensive bibliography. Fact sheets, articles, learning activities, full-color overhead transparencies, and duplicate slides are included within each topic area. The fact sheets display short summaries of current information and data. Scripts for the overhead color transparencies, an edited videotaped version of the proceedings of a national video conference for educators about global change, and a collection of satellite photographs of the earth's changing surface are also provided. (DDR)

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GLOBAL CHANGE EDUCATION RESOURCE GUIDE

VIDEOTAPE:

"GLOBAL CHANGE SCIENTIFIC OVERVIEW:

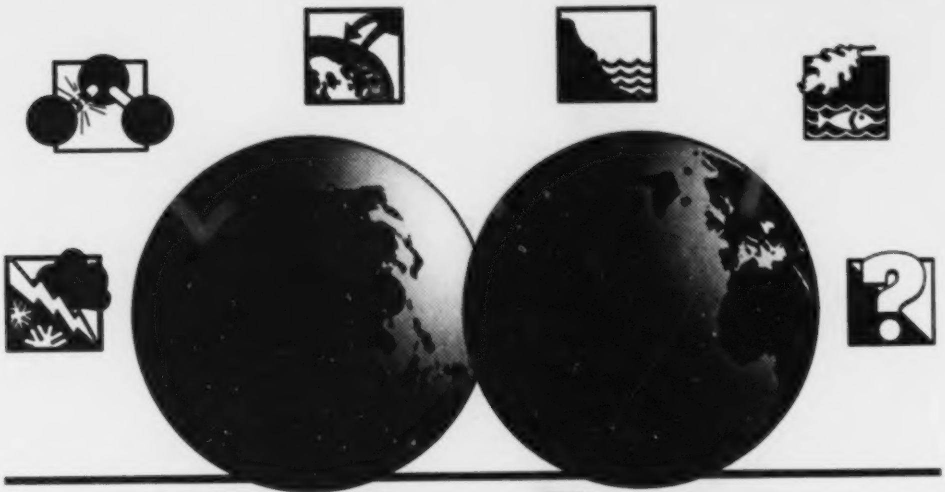
NATIONAL VIDEO CONFERENCE (83 MIN.)"

Resulting from a November 1994 national video conference on the same topics as the Global Change Education Resource Guide, an eighty-three minute edited version of the five hours of live broadcast was produced on videotape. Video conference downlink sites and workshops were organized by Sea Grant and Land Grant Programs in seven regions of the country with educators representing every state.

Featured scientists include:

- Dr. Robert Corell, National Science Foundation, "Global Change Overview";
- Dr. Berrien Moore, University of New Hampshire, "Natural Variability";
- Dr. Richard Gammon, University of Washington, "Greenhouse Effect and Ozone Depletion";
- Dr. Lisa Graumlich, University of Arizona, "Ecosystem Response";
- Dr. Dennis Meadows, Institute for Policy Analysis, "Population/Resource Consumption"; and
- Eileen Shea, National Research Council, "Policy Relevant Research."

The videotape is organized in fifteen minute segments for incorporation in instructional units on these topics. Funding for this project was provided by the U.S. Global Change Research Program, the National Oceanic and Atmospheric Administration, the National Sea Grant College Program, and the U.S. Department of Agriculture.



GLOBAL CHANGE EDUCATION RESOURCE GUIDE

INTRODUCTION

This Climate and Global Change Education Resource Guide was developed and funded by the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs as a contribution to the educational activities of the interagency U.S. Global Change Research Program (USGCRP). NOAA recognizes the importance of education, both formal and informal, in ensuring that the results of scientific research on global environmental issues like climate change and ozone depletion are effectively applied to individual and societal decision making. One of the most important responsibilities and greatest challenges to programs like the USGCRP involves the application of research results in the development of a scientifically and environmentally literate citizenry. This Education Resource Guide was developed as part of NOAA's continuing commitment to this great challenge and reflects a belief that improving the human partnership with the natural Earth system is essential to our future.

This Resource Guide is intended as an aid to educators who will conduct programs and activities on climate and global change issues for a variety of audiences. In some cases, these individuals will be involved in formal education at the K-12 level. Equally important are those individuals who provide informal educational opportunities to the general public through museums, aquaria, extension programs, and civic public interest groups. This Resource Guide is not intended to be a comprehensive presentation of the issues. Rather, it provides educators with a selected set of currently available materials which help to frame and clarify some of the key issues associated with changes in the global environment.

To prepare this Resource Guide, print and media materials on climate and global change issues were gathered from Federal agencies, non-profit and commercial organizations, environmental and educational associations, schools, community groups and international organizations. These materials were then subjected to a set of review criteria including: scientific accuracy and timeliness, consistency with national science education goals and standards, clarity, age appropriateness, and availability.

Individual sections of the Resource Guide were reviewed by scientists and program managers in NOAA. The complete Guide was subjected to a review by a selected set of experts active in the field of climate and global change research along with experts in the field of education. Activities included for classroom application were pilot tested with teachers and students.

The materials in the Resource Guide are organized by topic for ease in selecting and compiling presentations and duplicating pages for handouts. The topics are: Natural Climate Variability, Greenhouse Effect, Sea-Level Rise, Ozone Depletion, Ecosystem Response, and Decision-Making Under Scientific Uncertainty. Within each topic, fact sheets, articles, learning activities, full color overhead transparencies and duplicate slides are included.

The fact sheets display short summaries of current information and data on each topic. The fact sheets are part of a series produced by the Information Unit on Climate Change sponsored by the United Nations Environment Programme and the World Meteorological Organization. They are also available in Spanish, French, Chinese, Urdu, and Japanese.

Annotated bibliography along with information for acquiring additional resources, is included. Where possible, addresses, phone numbers, contact persons, and price information are noted.

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Atmospheric Administration
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GLOBAL CHANGE
EDUCATION RESOURCE GUIDE

Lynn L. Mortensen, Ph.D.

Editor

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NATURAL CLIMATE VARIABILITY

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An introduction to the climate system

▲ **The climate system is complex.** It is governed not only by what happens in the atmosphere, but in the oceans, the cryosphere (glaciers, sea ice, and continental ice caps), the geosphere (the earth's solid surface) and the biosphere (living organisms in the oceans and on land). The interactions among these various "spheres" are difficult to predict, not least because their respective processes occur on widely differing time scales. The typical equilibrium response times of the climate system's various components range from a single day to millenia.

▲ **Solar radiation is the only significant source of energy driving the climate system.** Because air is largely transparent to incoming short-wave solar radiation, this radiation does not directly heat the atmosphere very much. Instead, it warms the surface of the Earth. The surface then re-emits long-wave radiation that, because it *can* be absorbed by certain gases, warms the atmosphere.

▲ **The amount of warming that results from solar radiation depends in part on the nature of the earth's surface.** Ocean and land surfaces warm at different rates, and land covered by vegetation absorbs and reflects solar energy differently than do deserts or ice-caps. In this way, surface variations create complex patterns of surface energy distribution.

▲ **The oceans have an important influence on our present climate.** For example, wind-driven surface currents like the Gulf Stream carry large amounts of heat from the tropics to colder latitudes, which warms the atmosphere above. Other surface currents carry cold water towards the equator, which cools the atmosphere. Elsewhere, notably on the west coasts of continents, the winds blow away surface water; colder water from below wells up to replace it and cools the atmosphere.

▲ **Deep-ocean currents affect long-term climate variations.** Over most of the oceans, surface water is warmer, and so less dense, than the water beneath it. This discourages surface water from sinking downwards into the deep ocean. Only in certain regions, notably in the Antarctic and northwest Atlantic Oceans, does a combination of evaporation (which increases the water's salt content) and wintertime cooling make surface water dense enough to sink all the way down. This process of "deep-water formation" is still not fully understood, but it is clearly important. It is the primary mechanism whereby heat and dissolved carbon in surface water is transported down to the ocean depths, where they may remain for a thousand years or more. Changes in deep ocean currents may have caused natural climate fluctuations in the past, and their role in storing or releasing "excess" carbon could interact with man-made climate change in the future.

NATURAL CLIMATE VARIABILITY

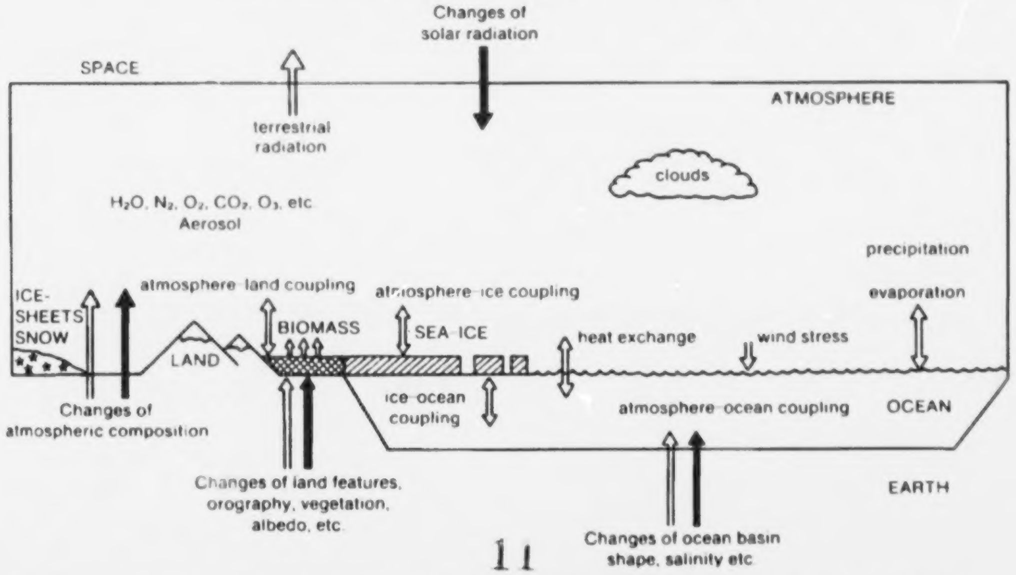
▲ **Ice reflects a significant amount of incoming solar energy back out into space.** So any changes to the amount of ice and snow on the earth — some climate models suggest that the Arctic Ocean's ice covering would all but disappear in a warmer climate — would affect the amount of solar energy absorbed by the earth's surface.

▲ **The biosphere's role in the climate system is not yet well understood.** The biosphere is made up of living organisms on land and in the seas. It helps to regulate climate through its role in the carbon cycle. Furthermore, land vegetation has a significant effect on surface reflectivity, heat, moisture, and energy. Because of the complexity of the biological processes involved, scientists can make only very general estimates of the biosphere's role in the climate system. Much more research will be needed before the biosphere's contribution to climate variation can be quantified.

▲ **Much still remains to be learned about the atmosphere as well.** Although the atmosphere has been widely studied and modelled (particularly by weather forecasters), large uncertainties remain concerning climate variability. One of the greatest unknowns is the role of clouds. Do they act to cool the earth by intercepting and reflecting solar energy, or to warm it by reducing outgoing terrestrial radiation? Satellite observations indicate that they probably do both, but their net effect on the present climate is very uncertain. It is even less clear how this net effect will change in response to global warming. Changes in cloud amount and cloud types might increase warming (positive feedback) or reduce it (negative feedback). A further unknown is exactly how the exchange of heat and gases between the atmosphere and other components of the climate system takes place.

▲ **Much more research is needed to enable scientists to better predict how climate change will come about.** According to the Intergovernmental Panel on Climate Change (IPCC – fact sheet 208), to improve our predictive capability, we need to understand better the various climate-related processes, particularly those associated with clouds, oceans, and the carbon cycle. We also need to improve the systematic observation of climate-related variables on a global basis; to investigate further past changes; to develop improved models of the Earth's climate system; to increase support for national and international climate research activities, especially in developing countries; and to facilitate the international exchange of climate data.

Schematic illustration of the climate system


Changes of solar radiation
SPACE
ATMOSPHERE
terrestrial radiation
clouds
H_2O, N_2, O_2, CO_2, O_3, etc
Aerosol
precipitation
evaporation
ICE-SHEETS SNOW
atmosphere-land coupling
atmosphere-ice coupling
BIOMASS
SEA-ICE
LAND
heat exchange
wind stress
Changes of atmospheric composition
ice-ocean coupling
atmosphere-ocean coupling
OCEAN
Changes of land features, orography, vegetation, albedo, etc
EARTH
Changes of ocean basin shape, salinity etc

Black arrows indicate external influences on the climate system. Open arrows indicate how the different components influence each other.

Source: J. Houghton et. al., eds. 'Climate Change: The IPCC Scientific Assessment', Cambridge (1990).

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An introduction to the science of man-made climate change

▲ **Certain gases in the atmosphere, such as carbon dioxide, play a crucial role in determining the earth's climate.** Although other factors are important as well, the composition of the atmosphere to a large extent controls our climate. Levels of so-called "greenhouse gases" are particularly important.

▲ **Greenhouse gases affect the "energy budget" of the climate system.** The earth receives energy continuously from the sun. It must get rid of this energy at the same rate by sending it back out to space. Greenhouse gases affect the ability of this outgoing energy to pass through the atmosphere. As their concentrations rise, the climate must somehow adapt, or change, to keep the energy budget in balance. One probable change (among others) is a warming of the earth's surface and the lower atmosphere.

▲ **Atmospheric concentrations of greenhouse gases are rising rapidly, mainly because of human activity.** By burning fossil fuels and deforesting the earth, mankind is increasing carbon dioxide levels. Intensive agriculture, coal mining, and leaky natural-gas lines are major sources of methane. Industrial products emit chlorofluorocarbons (CFCs). Nitrous oxide and low-altitude ozone levels are also increasing rapidly, for reasons that are less clear. Less than 200 years since we began making major emissions, greenhouse gas concentrations are rising to levels higher than any yet seen while humans have existed on this planet - and they will rise much further in the years ahead.

▲ **Changes in greenhouse gas concentrations have been associated with dramatic climatic changes in the past.** The last time greenhouse gas levels changed as much as they are changing now was when the earth emerged from the most recent ice-age. There is strong evidence that greenhouse gases played a significant role in that post-ice-age warming.

▲ **The current increase in greenhouse gases will affect the climate — but we don't yet know exactly how.** The different components of the earth's climate interact in complex ways, causing natural climate variations, many of which are still poorly understood. But even if we understood the present climate much better than we do, the future could still hold surprises. Due to the unprecendented rise in greenhouse gas emissions, we are entering into a new, hitherto unexplored, climatic regime.

▲ **Climate models indicate that one of the main effects of greenhouse gas emissions will be global warming.** Assuming that no action is taken to reduce emissions, computer models of the earth's climate indicate that global average surface temperatures will rise by 1.5-4.5°C over the next 100 years. This rise is larger and probably faster than any such change over the past 9,000 years. Climate models are far from perfect, and they rely on projections of future greenhouse gas emissions that are far from certain. But most scientists believe they provide the best estimates we have of future climate change. Emission scenarios and model predictions may overstate the risk, but they are equally likely to underestimate it.

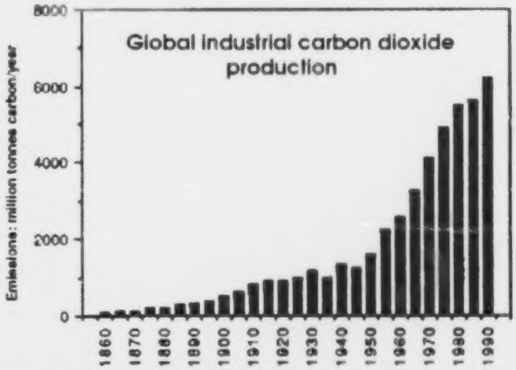
▲ **There is some evidence that this warming has already begun.** Average world surface temperatures appear to have risen by 0.3-0.6°C over the past 100 years. But although many climatologists believe that this indicates a real change, the historical temperature record is poor. Moreover, the climate varies naturally, and this observed warming is still within the range of natural variability. Nevertheless, this warming is also broadly in line with what models predict should have resulted from emissions to date.

▲ **Past greenhouse gas emissions have already committed us to more climate change in the future.** The climate does not respond instantly to emissions, and most greenhouse gases remain in the atmosphere for decades after being released, continuing to influence the climate. This built-in delay increases the risks in waiting for more conclusive evidence before acting to reduce emissions.

▲ **If no action is taken to reduce greenhouse gas emissions, the consequences for many of the world's societies and ecosystems may be serious.** Average sea-levels may rise, which would affect coastal communities through more frequent flooding and increased ground-water salinity. Changes in rainfall patterns and soil moisture levels are probable, but still difficult to predict. Both would have significant implications for agriculture.

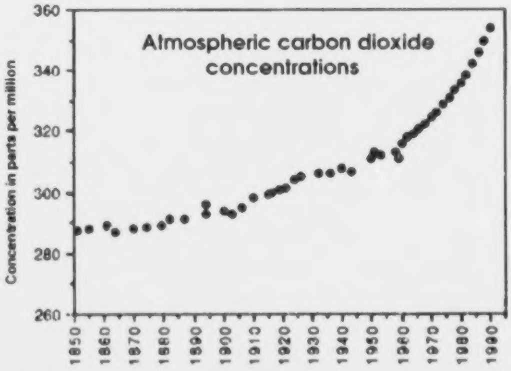
▲ **Those most at risk from climate change are likely to be those least able to adapt.** Not all climate change impacts will be negative. But for natural ecosystems and subsistence agricultural societies that have evolved over centuries to suit the present climate, any rapid change is likely to be traumatic.

▲ **Although uncertainties remain, we know enough to say with confidence that the risk of climate change is genuine and serious.** There is much that we still do not understand about the climate system and our impact on it. But the level of uncertainty in climate models should not be exaggerated. It is no greater than the uncertainty in the economic data and models on which equally far-reaching policy decisions must be based.



Global carbon dioxide emissions from fossil fuel combustion and cement manufacturing for the period 1860-1990. Bars show annual emissions at 5-year intervals. *Emissions stabilized in 1989-90 mainly due to the collapse of the former Communist economies but they are expected to increase again when these economies recover.*

Sources: Marland, CDIAC Communications, Winter 1989, 1-4, Oak Ridge National Laboratory, USA, 1989; IPCC 1992 Supplementary Report



Atmospheric concentrations of carbon dioxide, the most important greenhouse gas, from 1850 to 1990. *Before this century, carbon dioxide levels had not risen above 300ppm at any time in the past 100,000 years.*

Sources: Neftel *et al.* Nature, 331,609-611, 1988; Friedli *et al.* Nature, 324, 237-238, 1986; and Keeling *et al.* Geophys. Mon. 55, AGU, 165-236, 1989; IPCC 1992

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Why three hot summers don't mean global warming

- **The global temperature is rather like the level of unemployment: hard to define or measure, and easy to misunderstand.** Whenever the northern hemisphere has an unusually hot summer, newspapers attribute it to the greenhouse effect. Whenever it has a particularly cold spell in winter, the same papers ask "what happened to global warming?" Both lines are misleading.

- **Greenhouse gases are not the only factor affecting global temperatures.** Some of the other factors are also due to human activity; industrial emissions of sulfur dioxide, for example, may have a cooling effect. Still others are quite natural, such as volcanic eruptions (which can cool the climate temporarily) and variations in the energy output of the sun. Almost all climate models suggest, however, that the world's average surface temperature ought to have warmed somewhere between 0.4°C and 1°C since pre-industrial times as a result of the greenhouse gases emitted so far. So one of the clearest signs of man-made climate change would be the detection of such a warming. Figure A below, which graphs the global annual average temperature from 1861 to the present, does indeed seem to show a warming trend.[1] But such data must be interpreted carefully.

- **Natural climate variations make it difficult to distinguish long-term trends.** If there happened to be a natural temperature cycle which was at a minimum in 1861 and near a maximum at present, then plotting out temperatures over this time period and drawing a straight line through them could give a misleading impression of the trend. Take an analogy: if you made a series of hourly measurements of the brightness of the sun, starting at noon and ending at midnight two-and-a-half days later, you might well conclude that the world was getting darker — and you would be wrong. Of course, modern statistical techniques assume nothing so naive as a straight line. Instead, they attempt to explain observed variations in terms of a long-term trend (which may or may not be a straight line) as well as a set of fairly regular fluctuations about that trend. They thus reduce a complicated signal to a small number of fairly simple patterns.

- **State-of-the-art statistical methods indicate a global warming of approximately 0.45°C since the beginning of this century . . .** The thick line in figure A shows the underlying trend in global average temperatures obtained using such a "pattern-recognizing" statistical technique.[2] It isn't a straight line, but it clearly indicates a warming trend.

▲ **. . . but substantial fluctuations have occurred around this underlying trend.** This is particularly clear if we consider the most recent 30 years of the series (shown in figure B) and use these statistical tools to "filter" the data (in an effort to reduce the amount of random noise). The thick line in figure B shows the underlying trend again, and the thin line shows how the filtered signal fluctuates about that trend.

▲ **Natural temperature fluctuations seem to be occurring on several time-scales.** Some of these fluctuations may be due to natural climate oscillations and may therefore be fairly predictable. Others may be completely random. Data which has been filtered in this way must be interpreted with caution. But whatever their origin, figure B suggests that these natural fluctuations conspired to make the late 1980s particularly warm, much warmer than would have been expected on the basis of the underlying trend alone. It is quite possible that the world will cool over the next few years as the system "swings back" from the hot 1980s, even though the underlying trend remains upwards. These are very recent results, and aspects of them are still under debate.[3] But the basic message for non-statisticians is clear:

▲ **Three hot summers don't mean global warming, nor do three cold winters mean a new ice age.** The most statistics can tell us at present is that there does appear to be a genuine warming trend in figure A. Whether this trend is the effect of greenhouse gas emissions or of a natural fluctuation due to some as-yet-undiscovered mechanism cannot be determined from an analysis of the global mean temperature alone. Such natural, century-time-scale fluctuations appear to have occured in the past (although none in the last 9,000 years was as large as the *projected* change over the coming century). Unambiguous detection of climate change is likely to be a painfully slow process, involving much more detailed comparison of climate model results with observations.[4]

▲ **There is no climatic counterpart to the Antarctic ozone hole.** We must not expect a single, dramatic discovery to confirm "global warming" once and for all. If we wait for that discovery, we will wait for a long time — until well after it is too late to do much about it.

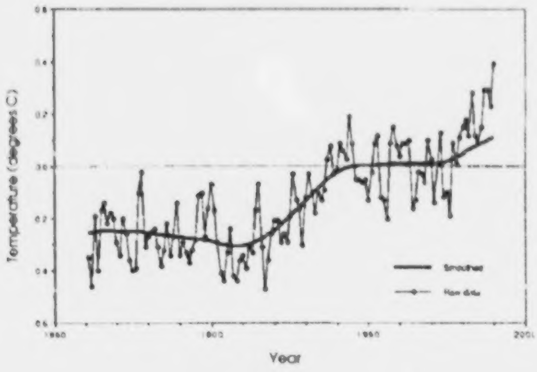
Notes:

[1] D. E. Parker & C. K. Folland, Proc. U.S. D.o.E. Workshop on Greenhouse-Gas-Induced Climate Change, Elsevier, 1990

[2] M. Ghil & R. Vautard, 'Nature', 350, March 1991, pp 324-327.

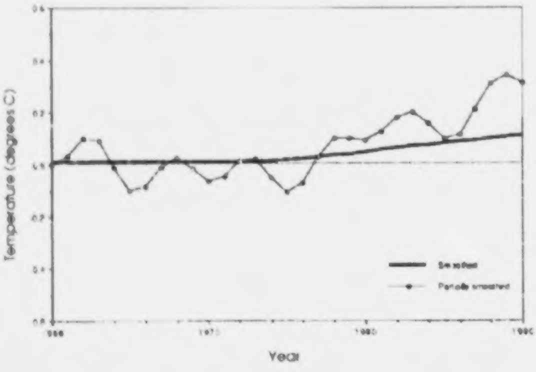
[3] J. Elsner & A. Tsonis: 'Nature', 353, October 1991, pp 551-553, and M. Allen, P. Read and L. Smith, 'Nature', 355, February 1992, p 686.

[4] T. Wigley and T. Barnett in J. Houghton, et al (eds.), 'Climate Change, the IPCC Scientific Assessment', chapter 8, pp.245-255, Cambridge, 1990.



A

***Global average temperatures from 1861 to 1990,** relative to the average for 1951-1980. (from IPCC updated consensus time-series provided by D.E.Parker, UK Meteorological Office). raw data (dots) and underlying trend obtained by singular spectrum analysis (thick line).*



B

***Global average temperatures from 1960 to 1990,** relative to the average for 1951-1980. underlying trend (thick line) and fluctuations about the trend, smoothed to emphasise wave-like variations (open dots).*

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Why "climate change" and "global warming" are not the same thing

▲ **Recent accounts of the scientific debate on climate frequently misrepresent what is being argued about.** They suggest that scientists are still discussing whether or not the climate is changing in response to greenhouse gas (GHG) emissions, as if there were a simple yes/no answer. So if a scientist questions the adequacy of present climate models, or fails to find conclusive evidence for global warming in a particular data-set, he or she is often reported as claiming that "there isn't really a problem". However, in most scientific circles the issue is no longer whether or not GHG-induced climate change is a potentially serious problem. Rather, it is how the problem will develop, what its effects will be, and how these can best be detected.

▲ **The confusion arises from the popular impression that "the enhanced greenhouse effect", "climate change", and "global warming" are simply three ways of saying the same thing**. They are not. No one disputes the basic physics of the "greenhouse effect". However, some of the consequences of the basic physics, including higher average temperatures due to "global warming", are less certain (although highly probable). This is because the fundamental problem concerns the way GHG emissions affect the flow of energy through the climate system, and temperature is just one of many forms energy takes.

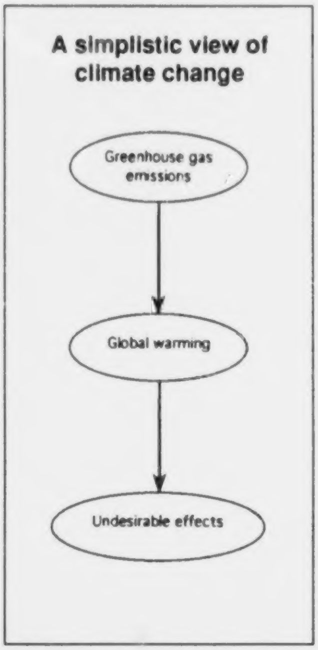
▲ **In the long term, the earth must shed energy into space at the same rate at which it absorbs energy from the sun.** Solar energy arrives in the form of short-wavelength radiation; some of this radiation is reflected away but, on a clear day, most of it passes straight through the atmosphere to warm the earth's surface. The earth gets rid of energy in the form of long-wavelength, infra-red radiation. But most of the infra-red radiation emitted by the earth's surface is absorbed in the atmosphere by water vapour, carbon dioxide, and other naturally occurring "greenhouse gases", making it difficult for the surface to radiate energy directly to space. Instead, many interacting processes (including radiation, air currents, evaporation, cloud-formation, and rainfall) transport energy high into the atmosphere to levels where it radiates away into space. This is fortunate for us, because if the surface could radiate energy into space unhindered, the earth would be more than 30°C colder than it is today: a bleak and barren planet, rather like Mars.

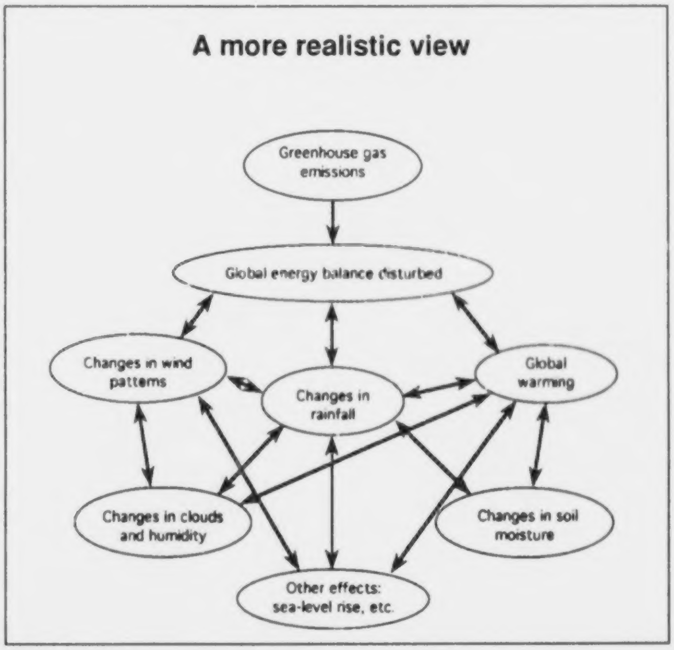
▲ **By determining how the air absorbs and emits radiation, greenhouse gases play a vital role in preserving the balance between incoming and outgoing energy.** Man-made emissions disturb this equilibrium. A doubling of the concentration of long-lived greenhouse gases (which is projected to occur early in the next century) would, if nothing else changed, reduce the rate at which the planet can shed energy to space by about 2%. Because it would not affect the rate at which energy from the sun is absorbed, an imbalance would be created between incoming and outgoing energy. Two percent may not sound like much, but over the entire earth it would amount to trapping the energy content of some three million tons of oil every minute.

▲ **The climate will somehow have to adjust to get rid of the extra energy trapped by man-made greenhouse gases**. Because there is a strong link between infra-red radiation and temperature, one probable adjustment would be a warming of the surface and the lower atmosphere. But it is important to realize that a warmer climate is not the only possible change, nor even necessarily the most important one. The reason for this is that radiation is not the only energy transport mechanism within the lower atmosphere (although it does play a vital, controlling role). Instead, the surface energy balance is maintained, and surface temperatures are controlled, by that complex web of interacting processes which transport energy up through the atmosphere. In contrast to the case of radiation, it is very difficult to predict how processes like cloud-formation will respond to greenhouse gas emissions.

▲ **Global warming is a symptom of climate change, but it is not the problem itself**. It may be the clearest symptom we have to look for, but it is important not to confuse the symptom with the disease. The fundamental problem is that human activity is changing the way the atmosphere absorbs and emits energy. Some of the potential consequences of this change, such as sea-level rise, will depend directly on how the surface temperature responds. But many of the most important effects, such as changes in rainfall and soil moisture, may take place well before there is any detectable warming.

▲ **If a scientist argues that the warming may not be as large or as fast as models predict, he or she is not suggesting that the problem of climate change should be ignored.** The point is only that this particular symptom — global average temperature — may be unreliable. We know that the air's radiative properties are changing, and we know that the climatic effects of this change will be profound. All climate models (fact sheet 14) indicate that the most significant change will be a global warming. But even if it isn't, other effects, equally profound, are inevitable. We are altering the energy source of the climate system. Something has to change to absorb the shock.


A simplistic view of climate change


A more realistic view

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How records from past climates support the case for global warming

▲ **One of the key problems in predicting climate change is determining how surface temperatures will respond to a given rise in greenhouse gas (GHG) concentrations.** This "climate sensitivity" not only depends on the direct effect of the GHGs themselves, but also on natural "climate feedback" mechanisms, particularly those due to clouds, water vapour, and snow cover. Each of these may change in response to global warming and might therefore act either to enhance or to suppress any temperature rise. Climate models suggest that water vapour and snow cover, at least, are "positive feedbacks" and so should enhance the warming. Nevertheless, an estimate of total climate sensitivity that considers all feedbacks is crucial for checking these model results.

▲ **Past climates have left records in ice and ocean-sediment cores that provide some of the best available evidence.**[1] A couple of kilometres beneath the surface of the Antarctic and Greenland ice-sheets lies ice which has been there for tens of thousands of years. Ocean sediment records go back even further. As sediments form on the floor of the ocean and snow piles up, trapping air bubble into ice, they store information concerning the climate of their day and the factors which affected it. The figure below shows that temperatures have varied closely with GHG concentrations for most of the past 100,000 years. The problem then arises, was this because GHG levels caused the temperature to change, or the other way around? Scientists can attempt to answer this question, but as yet only tentatively.

▲ **Scientists have learned that several factors affect the earth's climate.** The various "climate-controlling" factors operate on very different time-scales. The slower-acting factors are the earth's orbital movements around the sun and the expansion and retreat of the polar ice caps. The faster-acting ones are atmospheric dust; changes in ocean circulation; feedbacks due to water vapour, clouds, and snow; and the concentrations of greenhouse gases.

▲ **Variations in the earth's orbital movements around the sun create very slow climate cycles.** The earth "wobbles" slowly on its axis, rather like a spinning top which is about to fall over. Called "Milankovich cycles", these wobbles affect the amount of solar energy the Earth receives and where that energy is deposited. This in turn affects the climate, introducing regular cycles with periods of up to 100,000 years. They are the main factor behind the onset and retreat of the ice-ages. Scientists can tell from basic astronomical theory how Milankovich cycles have evolved over the past hundreds of thousands of years.

▲ **The ice-sheets affect the climate by reflecting sunlight.** All other things being equal, the more ice on the earth, the colder it is, because ice reflects sunlight better than does any other surface covering. So during an ice-age, the global temperature is cooler than it would be due to Milankovich cycles alone, because the ice-sheets reflect solar energy. Scientists estimate the past volume of ice-sheets in the following way: As water freezes, different isotopes (types of chemicals) tend to freeze out at different rates. If a lot of water is bound up in ice-sheets, oceanic concentrations of the slowest-freezing isotopes rise. By looking at the concentrations of these isotopes in marine sediments, scientists can work out how much ice was around when they were formed.

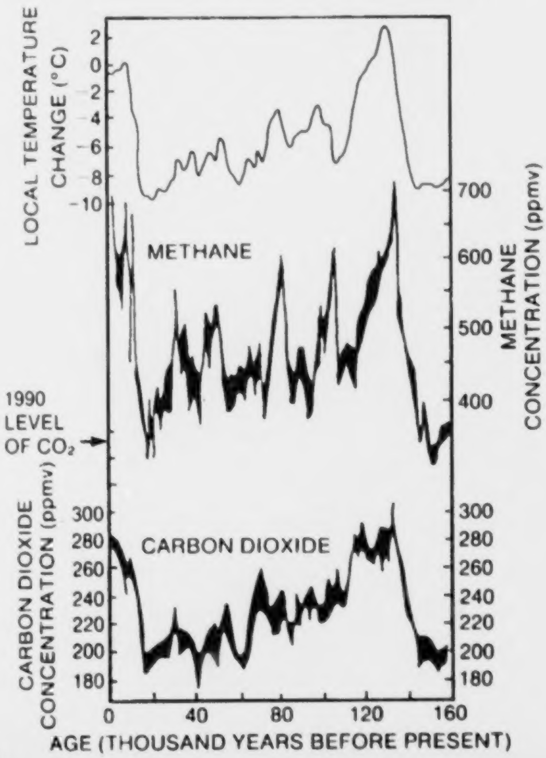
▲ **Three other factors — dust, water, and greenhouse gases — have a much more rapid impact on climate.** The amount of dust in the atmosphere depends mainly on volcanic activity. Dust levels in past climates can be estimated from the ice surrounding bubbles trapped in ice-cores. Greenhouse gas concentrations may be found by analysing the bubbles themselves. This leaves all other feedbacks including changes in ocean circulation, water vapour, clouds, and snow as the undetermined factors in past climate changes.

▲ **Ice-cores can also tell us about past temperatures.** Because different isotopes of water freeze at different rates at different temperatures, ice composition depends on the temperature at which it formed. Analysis of Antarctic ice tells us about past temperatures in the snow-formation region above the Antarctic. This isn't the same as knowing the global temperature, but there is some evidence that Antarctic temperatures and global temperatures rise and fall together.

▲ **Knowing how these factors have changed, and knowing the temperature response, scientists can deduce the role of the remaining factors.** This assumes of course that there is only one equilibrium temperature corresponding to a given array of "settings" for these climate-controlling factors. That might not be the case: first, because there might be another factor which scientists haven't thought of, and second, because the temperature might not depend on the current settings of the climate-controlling factors alone, but also on previous settings.

▲ **Making these assumptions gives a value for climate sensitivity consistent with that found by climate models.** These models suggest that if the net effect of ocean circulation, water vapour, cloud, and snow feedbacks were zero, the approximate temperature response to a doubling of carbon dioxide from pre-industrial levels would be a 1°C warming. However, after taking into account changes in the three other climate-controlling factors that we know about - orbital changes, ice caps, and dust - a comparison of past temperature changes with past changes in GHG concentrations indicates that such a doubling of CO_2 would actually result in a warming of 3°C or more. Assuming that scientists haven't left out anything vital, this suggests that the net effect of water-based feedbacks is positive and would amplify GHG-induced warming by more than a factor of two.

▲ **Many assumptions have been made, but the historical evidence increases our confidence in model results.** Ice-core record analysis suggests that changes in GHG concentrations are associated with short-term (century time-scale) temperature changes, strongly amplified by cloud, snow, and/or water vapour feedbacks. This is in remarkably good agreement with the picture given by climate models.



Notes

[1] C. Lorius et al: "Nature", 347 (1990), pp. 139-145.

Evidence of a link. *Carbon dioxide and methane levels over the past 160 thousand years, from analysis of air trapped in Antarctic ice-cores, compared with variations in local temperature inferred from the isotope record.*

Source: IPCC

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How the oceans influence climate

▲ **The oceans influence climate over long and short time-scales.** On the longest time-scale of geologic time, the shape and location of the continents helps to determine the oceans' circulation patterns. Since continental plates drift at about 5 cm per year and mountain ranges rise by about 1 mm, it usually takes millions of years for new land formations to change the oceans. Patterns of ocean circulation and up-welling can also change much more rapidly, resulting in climate variations and fluctuations on a human time-scale. Records of global and, in particular, regional climate show periods lasting from years to centuries during which the climate was systematically different from earlier and later periods. Scientists believe that this behaviour is related to changes in the way the oceans store and transport heat, although the precise causes of these changes are not always clear.

▲ **The oceans and the atmosphere are tightly linked and together form the most dynamic component of the climate system.** Changes in external factors such the sun's energy, the distribution of various plant species, or the emission of greenhouse gases into the atmosphere can alter the temperature and circulation patterns of the atmosphere-ocean system. Because the atmosphere and oceans are turbulent, they can also generate their own internal fluctuations. Short-term fluctuations in wind or temperature (that is, weather) can directly influence the currents and temperature of the underlying ocean, while oceanic fluctuations can magnify, diminish, or modify atmospheric fluctuations.

▲ **The oceans play a critical role in storing heat** (and carbon — see fact sheet 21). When the earth's surface cools or is heated by the sun, the temperature change is greater —and faster — over the land than over the oceans. Because it is a fluid, the ocean diffuses the effects of a temperature change for great distances via vertical mixing and convective movements. The solid land cannot, so the sun's heat penetrates only the thin, upper crust. One consequence of the ocean's ability to absorb more heat is that when an area of ocean becomes warmer or cooler than usual, it takes much longer for that area to revert to "normal" than it would for a land area. This also explains why "maritime" climates tend to be less extreme than "continental" ones, with smaller day-night and winter-summer differences.

▲ **The ocean's waters are constantly being moved about by powerful currents.** Surface currents are largely wind-driven, although the rotation of the earth, the presence of continents, and the oceans' internal dynamics also have a strong influence. Deep-ocean flow (and, to a lesser extent, surface flow) is driven by density differences produced by heating and cooling and by precipitation and evaporation (cool saline water is denser than warm fresh-water). The behaviour of the atmosphere strongly affects these density differences. For example, clouds can cool the sea by blocking the warming rays of the sun or reduce surface salinity by bringing rain. The wind can influence evaporation rates by blowing more strongly or more weakly.

▲ **These currents influence the climate by transporting heat.** Horizontal currents, particularly those moving north or south, can carry warmed or cooled water as far as several thousand kilometres. The displaced water can then warm or cool the air and, indirectly, the land over which this air blows. For example, water from the tropical and subtropical Atlantic (including some from the Gulf of Mexico) moves north through the Atlantic in a current popularly (if misleadingly) called the "Gulf Stream". There it bathes the shores of Western Europe, producing a climate that is surprisingly mild for that latitude. In addition to currents, up-wellings of cold water in places where the wind blows surface water away can also affect climate. Thus San Francisco, influenced by coastal up-welling, is hardly warmer than Dublin, which is influenced by the Gulf Stream, despite being over 1,600 km further south.

▲ **Currents involved in "deep-water formation" are particularly important for climate.** In winter, surface cooling causes water to become more dense. (While fresh-water that is cooled starts to expand at temperatures below 4°C, salt-water continues to compress all the way down to its freezing point of -2°C.) In areas where evaporation exceeds precipitation, the resulting rise in salinity also increases density. When the surface water becomes denser than the underlying water, "convective overturning" occurs and the dense surface water mixes downwards. In certain places this downward mixing can occasionally extend all the way to the bottom, even in deep oceans. The dense, deep water thus formed spreads out over the whole ocean. As a result, when downward mixing takes place at high latitudes it creates a circulation pattern in which warm water from tropical and subtropical regions moves poleward, surrenders heat to the atmosphere, cools and sinks, and flows back towards the equator. The net result is a transport of heat poleward.

▲ **An apparently small change in just one aspect of the ocean's behaviour can produce major climate variations over large areas of the earth.** The areas of cold-water formation are one known example of this possibly wide-spread phenomenon. Although more research is needed, there is some agreement among oceanographers that, for the entire area north of 30°N latitude, the ocean's poleward transport of heat is the equivalent of about 15 watts per square metre of the earth's surface (W/m^2). This can be compared with some 200 W/m^2 from direct sunshine, and about 6 W/m^2 for what climate change models predict will happen if the atmospheric concentration of carbon dioxide doubles. Recent observations, ocean core records, and some modelling results indicate that North Atlantic deep-water formation and its associated ocean heat flow fluctuate substantially over time-scales ranging from years to millennia. The system is vulnerable because even a relatively small decrease in surface salinity prevents water — no matter how cold it is — from sinking. This could occur if there is a flood of fresh-water run-off from the Arctic due to global warming.

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El Niño

S. George Philander

"The sea is full of wonders, the land even more so. First of all the desert becomes a garden...."

When a group of experts met in Princeton, New Jersey, in October 1982 to discuss plans for an international program to study El Niño, they did not suspect that the most intense and devastating El Niño of the past century was even then forming in the Pacific Ocean. Less than a decade later, scientists were able to predict months in advance that El Niño conditions would develop toward the end of 1991. The phenomenon begins with relaxation of the usually intense westward trade winds that drive westward equatorial surface currents and expose cold water to the eastern Pacific surface. When the winds relax, warm surface waters that have been piled up in the western Pacific surge eastward.

As a result, during the early months of 1992 there were abnormally high sea-surface temperatures in the eastern tropical Pacific Ocean, coastal and equatorial upwelling ceased, and torrential rains fell. Even Texas and southern California suffered devastating floods.

Oceanographic Aspects of El Niño

The term El Niño originally referred to a warm, southward-flowing current that moderates low sea-surface temperatures off the coast of Ecuador and Peru during the early months of the calendar year, shortly after Christmas. (The Spanish term *El Niño* refers to the child Jesus.) Every few years the current is more intense than normal, penetrates unusually far south, is exceptionally warm, and is accompanied by very heavy rains. At first these years were known as *años de abundancia* (years of abundance) when

> *The sea is full of wonders, the land even more so. First of all the desert becomes a garden....The soil is soaked by the heavy downpour, and within weeks the whole country is covered by abundant pasture. The natural increase of flock is practically doubled and cotton can be grown in places where in others years vegetation seems impossible.*
>
> [R.C. Murphy, Oceanic and Climatic Phenomena Along the West Coast of South America During 1925. *Geographical Review*, 1926.]

At present, the term El Niño is not associated primarily with a joyous event, but with ecological and economic disasters. Because economic development, including fisheries that exploit the abundance of fish in the usually cold waters of Peru, are vulnerable to El Niño's climate changes, there is now a pejorative view of what once was a joyous occasion.

Not until the 1960s did oceanographers realize that the unusually warm

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surface waters off the coast of Peru during El Niño extend thousands of kilometers offshore, and are but one aspect of unusual conditions throughout the upper tropical Pacific Ocean. Tide-gauge data collected by Klaus Wyrtki (University of Hawaii) provided one of the first indications that El Niño is a consequence of changes in the winds that drive the ocean.

The lower panels of the figures on the following pages show schematically what happens in the ocean. During periods of intense trade winds, warm surface waters are piled up in the western tropical Pacific (so that sea level is high there) while cold water is exposed to the surface in the east. Surface currents at the equator are intense and westward during such periods. When the trade winds relax, as happens during El Niño, the warm surface waters in the west surge eastward so that isotherms shoal in the west and deepen in the east. The westward surface currents at the equator now weaken and often reverse direction, redistributing warm surface waters eastward. Details of this redistribution depend on the way in which the winds relax, and involves currents and oceanic waves that slosh back and forth across the Pacific. By studying the response of each of the three tropical oceans to seasonal wind changes—for example, the monsoons over the Indian Ocean—oceanographers have learned much about the processes controlling the ocean's adjustment to wind changes, and they have developed computer models that realistically simulate the oceanic response. If wind changes during a certain period are specified, then the models accurately reproduce El Niño conditions during that period. One of these models is now being used operationally at the National Meteorological Center in Washington, DC, to describe conditions in the tropical Pacific each month.

[illegible]

The Southern Oscillation

From an oceanographic point of view, El Niño is caused by changes in the surface winds over the tropical Pacific Ocean. But what causes the interannual (year-to-year) wind fluctuations? Efforts to describe these fluctuations, and, more generally, to document interannual circulation variations in the tropical and global atmosphere, started toward the end of the 19th century. Gilbert Walker, who became director-general of observations in India in 1904 (shortly after the famine of 1899 when the monsoons failed), initiated this research in an attempt to predict monsoon failures. He knew of evidence that interannual pressure fluctuations over the Indian Ocean and eastern tropical Pacific are out of phase: "When pressure is high in the Pacific Ocean it tends to be low in the Indian Ocean from Africa to Australia," he wrote.

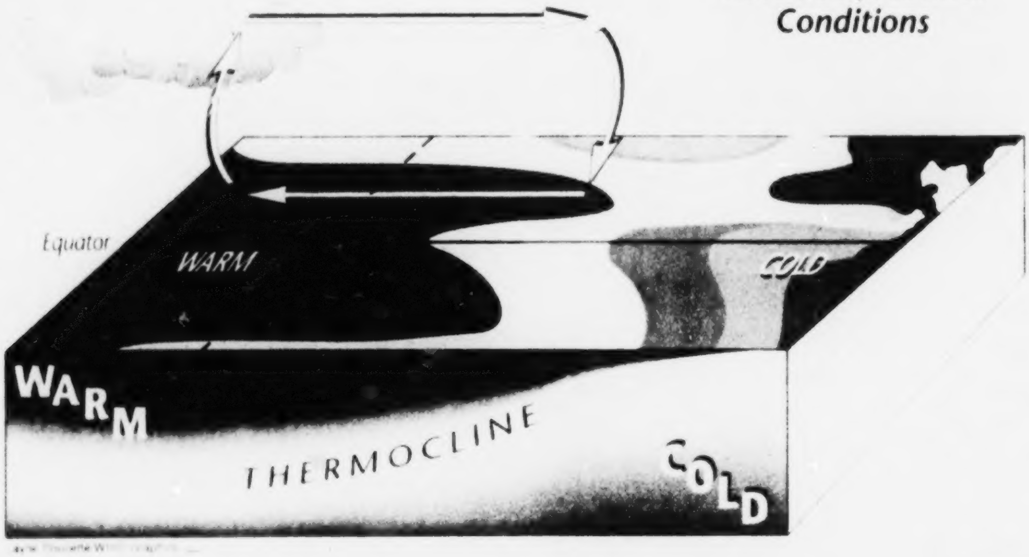
This irregular interannual oscillation, which he named the Southern Oscillation, led Walker to believe that the monsoons are part of a global phenomenon. He set out to document the oscillation's full scope, in the hope that it held the key to monsoon prediction. Walker found that the Southern Oscillation is correlated with major changes in rainfall patterns and wind fields over the tropical Pacific and Indian oceans, and with temperature fluctuations in southeastern Africa, southwestern Canada, and the southern US. Attempts to translate these findings into monsoon predictions failed, and Walker's contemporaries expressed doubts about the statistical relations inferred from relatively short records. Many years later the analysis of much longer records resoundingly vindicated Walker.

The sea-surface temperature data available to Walker were inadequate to determine whether the ocean is involved in the Southern Oscillation. Confirmation that this is so came in 1957 and 1958, during the International Geophysical Year, when El Niño occurred. It was noted that unusually warm surface waters were not confined to the coast of South Africa, but extended far westward. This coincided with weak trade winds and heavy rainfall in the central equatorial Pacific, a normally arid region. Jacob Bjerknes (University of California, Los Angeles) proposed that the coincidence of unusual oceanographic and meteorological conditions is not unique to 1957 and 1958, but occurs interannually, and that El Niño is in fact one phase of the Southern Oscillation. (An apposite term for the complementary phase is La Niña.) Bjerknes furthermore proposed that, from a meteorological perspective, the interannual Southern Oscillation is caused by changes in sea-surface temperature. Over regions of high sea-surface temperatures (and high land temperatures) the air tends to rise so that low-level winds converge onto these areas. The winds carry moisture, evaporated from the ocean; when this moisture-laden air rises, condensation, clouds, and heavy precipitation result. During La Niña, the region of rising air is confined to the western tropical Pacific where sea-surface temperatures are high. During El Niño, the warm surface waters spread eastward and so does the region of heavy rainfall. Models of the atmosphere can now simulate the interannual Southern Oscillation between cold, dry La Niña and warm, wet El Niño, provided the interannually changing sea-surface temperature patterns are specified.

Atmosphere-Ocean Interactions

While oceanographers believe El Niño is caused by a relaxation of the trade winds, meteorologists attribute the change in the winds to the change in sea-surface temperatures. Bjerknes first realized that this

In a normal year, intense westward winds (white arrows) drive westward equatorial currents that push warm Pacific surface waters steadily to the west and expose colder waters, upwelling from the deeper water column, to the surface in the east. (After Verne Kausky, National Meteorological Center.)



circular argument implies that interactions between the ocean and atmosphere are at the heart of the matter, and that a change in one medium affects the other. Suppose, for example, that during a period of intense trades, a small disturbance causes those winds to relax somewhat. Some of the warm surface waters that are piled up in the west will tend to surge eastward. The associated change in the sea-surface temperature pattern will cause a further relaxation of the winds so that even more warm water moves eastward.

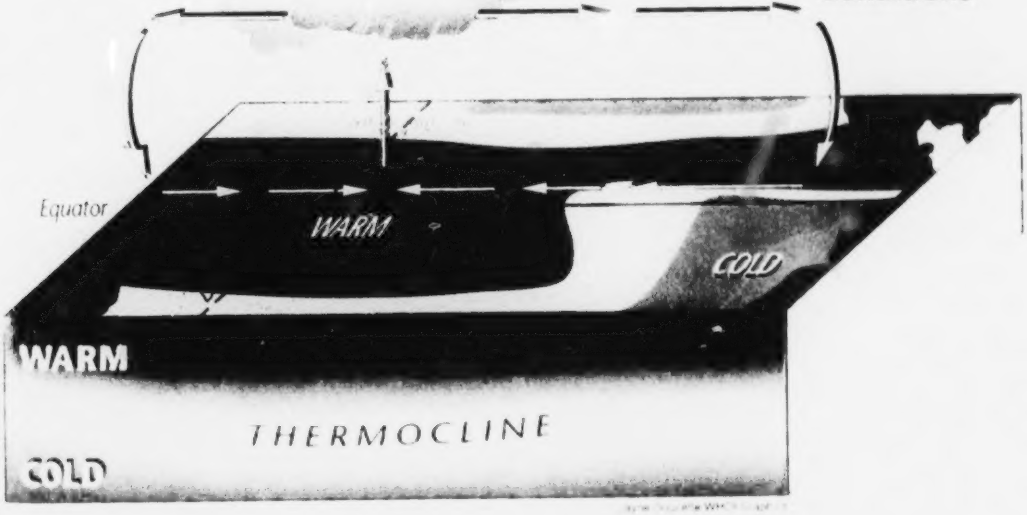
Such positive feedbacks between the ocean and the atmosphere can lead to El Niño. During the process, the atmosphere responds rapidly, within a matter of days or weeks, to changes in sea-surface temperatures. The ocean, however, takes far longer (many months) to adjust to a change in the winds. It is this "memory" of the ocean that makes the Southern Oscillation continual. The oceanic conditions at a certain time are not simply determined by the winds at that time, but also depend on winds at earlier times. During El Niño, for example, the ocean has a "memory" of winds that prevailed during La Niña, and it is the delayed responses to those winds that brings about the termination of El Niño and introduces the next La Niña.

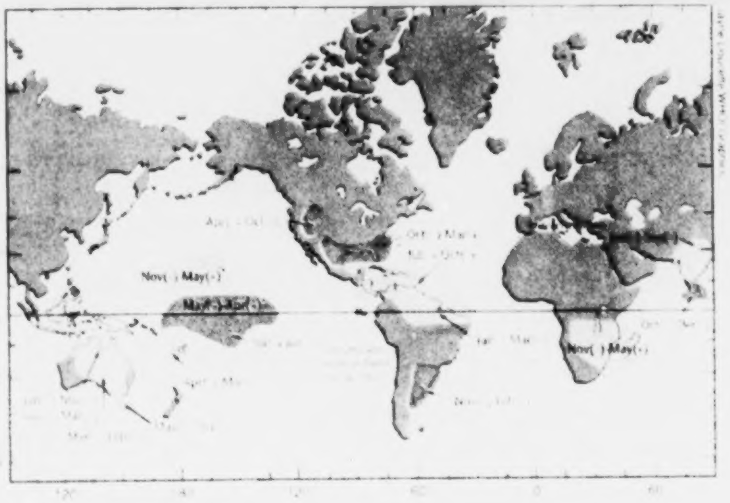
Successful prediction of the 1991 El Niño is convincing evidence of rapid progress during the 1980s in our ability to monitor and predict conditions in the tropical Pacific. The National Meteorological Center now issues not only daily weather forecasts, but also monthly reports that describe surface and subsurface oceanic conditions in the tropical Pacific. This new era of operational oceanography promises to put oceanography on a par with meteorology.

For a long time there has been a sharp contrast between the paucity of oceanographic data and the vast amount of meteorological data flowing continually from a global network of instruments, including satellites. The principal justification for atmospheric data collection is the

In an El Niño year, the trade winds relax, allowing a surge of warm water eastward across the Pacific and changing the characteristics of waters in the eastern part of the ocean basin. (After Verne Kausky, National Meteorological Center.)

December, El Niño Conditions





During an El Niño, precipitation is enhanced in some (pink) areas and diminished in other (yellow) regions. The months indicate when these regions are affected, typically coinciding with local rainy seasons. The year that unusually high sea-surface temperatures first appear is indicated by (-); (+) refers to the following year. (After Ropelewski and Halpert, 1987.)

need to predict the weather. Although the prediction of certain changes in the oceanic circulation (for example, Gulf Stream meanders) serves navigational needs, the most compelling reason for operational oceanography is the need to predict climate fluctuations—El Niño, the difference between one winter or summer and the next, prolonged droughts, and so forth. Such forecasts require coupled atmosphere-ocean models. They start from an accurate description of atmospheric and oceanic conditions at a certain time, and predict how conditions will develop thereafter. Atmospheric descriptions are based on measurements that are interpolated by a realistic computer model to produce global maps of different fields—temperature and winds, for example.

During the past decade, oceanographers have implemented a similar operational system for the tropical Pacific Ocean. The network of instruments that provide data in real time to the Global Telecommunication System includes expendable bathythermographs released by voluntary observing ships, tide gauges on numerous islands, and, in the central tropical Pacific where there are neither islands nor commercial ship tracks, an array of moorings with thermistor chains (TOGA-TAO moorings) and, in some cases, current meters (see Climate Prediction and the Ocean, page 66). A numerical model of the tropical Pacific, capable of realistic simulations of oceanic conditions, assimilates the various measurements and each month produces maps that describe oceanic conditions (surface and subsurface temperatures and currents). These maps are the oceanic counterparts of daily weather maps and depict the evolution, month by month, of El Niño and complementary La Niña conditions in the tropical Pacific Ocean. Because of the success of this effort, operational activities are now being expanded to the global oceans. This development promises considerable benefits for oceanography—however, not everybody welcomes it enthusiastically.

Many oceanographers believe that it is premature to attempt operational oceanography. They agree that it may be possible in the tropics but argue that, for other regions, oceanic computer simulations are still too crude and the oceanographic data collected on a regular basis are too sparse. The skeptics do not appreciate the extent to which the obligation

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to predict El Niño contributed to rapid progress in tropical oceanography, especially the availability of more data. Samuel Johnson observed that capital punishment concentrates the mind wonderfully. The same can be said of the obligation to make predictions on a regular basis. In the case of El Niño it has led not only to improved models of the tropical Pacific, but also to much more accurate information about the winds that drive the oceans. (The winds, from realistic atmospheric models, received little attention until oceanographers started to use the models and pointed out their deficiencies.)

There is no doubt that attempts at realistic simulations of other parts of the oceans, month after month, will also lead to improved models. As I mentioned, these simulations start from an accurate description of oceanic conditions, a description that requires measurements. In the case of the tropical Pacific, it was clear that there was a need for a TOGA-TAO array to measure subsurface temperatures in the remote central equatorial Pacific. Such an array has been installed, and now transmits its data to certain centers by satellite, twice a day. Operational oceanographic activities for other parts of the oceans are also likely to provide convincing justification for improved global ocean monitoring.

In the current debate about the feasibility of operational oceanography, nonscientific factors seem to play a significant role. Many oceanographers share the sentiments expressed by John Masefield:

> *I must go down to the seas again, to the lonely sea and the sky,*
> *And all I ask is a tall ship and a star to steer her by....*

They are appalled by the prospect of an impersonal, mammoth computer model of the ocean that demands data every 12 hours from all ships, short and tall, at sea. There would indeed be an unfortunate diminution in the romance of the oceans if operational oceanography were to replace the traditional methods of measurements. That, however, will not happen. Both approaches are essential. The ocean is so immensely complex that even the most sophisticated model, many years hence, will still have serious deficiencies. Research expeditions on ships with evocative names—*Atlantis, Discovery, Meteor*—to study poorly understood phenomena and processes will always be necessary to learn more about the oceans and improve the models.

The skeptics do [illegible]

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NEWS AND VIEWS

CLIMATE CHANGE

Don't touch that dial

J. W. C. White

At a time when superlatives are routinely used to describe the mundane, it is difficult to express the importance of two papers in this issue which present results from the new GRIP ice core in central Greenland. The GRIP Project Members[1] and Dansgaard *et al.*[2] (pages 203 and 218, respectively) give us our first detailed look at the last interglacial period, and it is not what we expected.

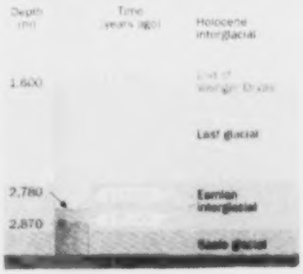
As an uncertain climate lies before us, we have been looking warily over our shoulders to see how the climate system has behaved in the past. For 10,000 years, the Earth has enjoyed an interglacial period, a time of steady and dependable climate. Further back, during the last ice age (which lasted about 100,000 years), and in the transitional period, it is now accepted that the climate 'flickered' rapidly. But we could take comfort from the thought that dramatic changes occurring in decades or even years were probably triggered in some way by the massive glaciers or huge extensions of sea ice present at the time.

Now the Greenland Ice-core Project (GRIP) team have removed this sense of security. Using a variety of evidence drawn from the ice core — stable isotope ratios, chemical and physical properties, and greenhouse gas concentrations in trapped air bubbles — they demonstrate that very rapid shifts in temperature and greenhouse gases are also possible in interglacial periods.

Our view of climate on the timescale of glacial cycles is shaped by the tools we use to construct that view. Up to now, our ideas of interglacial periods have come from three sources. First and foremost is our knowledge of our own Holocene interglacial, drawn from sources such as tree rings, historical records and pollen samples, to name but a few. Then there are the ocean sediment cores which document numerous interglacials over the past million years. Third, there is the Vostok ice core, until now the only deep core to have yielded easily datable ice from the previous interglacial period (known as the Eemian) which stretched from about 135,000 to 115,000 years ago.

In ocean cores the stirring of the sediment surface by benthic life homogenizes the oceanic record so that the minimum resolution is no better than a thousand years. In the Vostok core, the low accumulation rate of snow and thinning of the annual layers with depth means that climate changes of a century or less are difficult to resolve; flickers may have occurred that cannot now be detected. (There is a compensation: the Vostok core should take the record back to about 500,000 years ago, twice the age of the oldest Greenland ice[3], and covering several glacial to interglacial cycles.)

The new Greenland ice cores GRIP and GISP2, in contrast, were drilled in regions of high snow accumulation near the centre of the Greenland ice sheet. With these cores, designed to concentrate on the past 200,000 years, we can see climate changes on the timescale of decades or less, even though they occurred a hundred thousand years ago. The indicators of climate change range from local (for example, temperature, deduced from its effect on stable isotope ratios), to regional and hemispheric (such as airborne dust concentrations and chemical composition), to global (greenhouse gas compositions).



Depths of time — the GRIP ice core

The Eemian period falls in the interval from 2,780 to 2,870 cm down, well above bedrock. Blurred in the Vostok core, it now comes into focus and it is strikingly different from the Holocene. Holocene climate appears to have one, and only one, state, whereas the new results show that the Eemian had three. The middle state matches our own Holocene climate. A significantly colder state and a significantly warmer state existed in the Eemian. On average, temperatures were 2 °C higher than at present. It apparently took very little time, perhaps less than a decade or two, to shift between the states, and the states appear to be stable sometimes for thousands of years and sometimes for only decades. We don't know which is the norm for interglacial periods: the stable, one-state Holocene or the multiple-state, rapidly changing Eemian. We do know that answering this question will be a priority for global change research.

When evidence from the sister core of GRIP, the GISP2 core[4,5], showed earlier this year that aspects of the climate system could shift from glacial conditions to interglacial conditions in a few years, there was always the solace that such changes were characteristic of glacial times, and not really analogues of the future. In our interglacial age, we do not expect the polar front in the North Atlantic rapidly to dip down to Spain with sea ice expanding in behind it, plunging adjacent land, particularly Northern Europe, into glacial-like cold. We do not have massive lakes formed by retreating glaciers, lakes which may catastrophically drain into the North Atlantic, disrupting deep water formation and the transfer of heat northward.

The new ice core results bring rapid climate change to our doorstep: changes of up to 10 °C in a couple of decades, or perhaps in less than a decade, appear possible in interglacials. Given our ongoing 'global experiment' of increasing greenhouse gas concentrations via fossil fuel burning, is the Eemian warm state a glimpse at our future climate? Whatever the answer to that question, the speed with which the climate system can shift states gives us pause. Adaptation — the peaceful shifting of food growing areas, coastal populations and so on — seemed possible, if difficult, when abrupt change meant a few degrees in a century. It now seems a much more formidable task, requiring global cooperation with swift recognition and response.

How unusual is the climate stability of the Holocene? Dansgaard and colleagues[2] investigated one of the possible tracers, the oxygen isotope ratio (a proxy for atmospheric temperature) along the whole of the GRIP core (see figure). Throughout the last glacial period, the Eemian interglacial and the glacial before that, they found rapid oscillations in the isotope ratio. Because of the way that ice thins with age, they could look in detail at the Holocene, and found that the swings have been much smaller, by a factor of 3 to 4, than those earlier flickers. At no time during the Holocene has Eemian-like climate change occurred.

We humans have built a remarkable socio-economic system during perhaps the only time when it could be built, when climate was stable enough to let us develop the agricultural infrastructure required to maintain an advanced society. We don't know why we have been so blessed, but even without human intervention, the climate system is capable of stunning variability. If the Earth had an operating manual, the chapter on climate might begin with a caveat that the system has been adjusted at the factory for optimum comfort, so don't touch the dials. ☐

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1. GRIP Project Members *Nature* **364**, 203–207 (1993).
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NEWS AND VIEWS

CLIMATE

Flickers within cycles

Scott Lehman

CRUDELY, the Earth's climate seems to come in two states — glacial and interglacial — that persist for thousands to tens of thousands of years. But signs of much shorter-period variations are crowned in this issue[1], with the report of climate 'flickers' lasting as little as 10 years or less throughout much of the past 40,000 years.

The results, reported by Taylor *et al.* on page 432, are the first data to come from the GISP2 (Greenland Ice Sheet Project 2) group which has been drilling at Summit on the Greenland Ice Sheet for the past four years. The GISP2 core is one of two being recovered as part of an international effort to monitor a variety of climate proxies and atmospheric gases locked away within the ancient ice. The location (at 3,230 metres) was chosen, as an improvement on earlier drill sites, to provide greater stratigraphic resolution and length of record, fewer disturbances due to ice flow, and to obtain ice less likely to have been affected by summer melting — an important source of uncertainty in CO_2 measurements. A key reason for studying two cores in parallel is to aid in distinguishing the common climate signal from glaciological and analytical noise, an increasingly difficult distinction as quantities within the ice are measured on the seasonal-to-annual timescales resolved by the new cores.

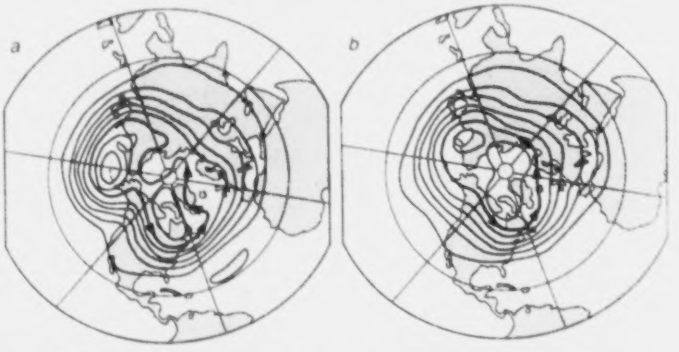
The European consortium (GRIP) presented its first results last September[2]. Their ^{18}O measurements established that the climate was bistable during much of the last ice age, showing that every 500 to a few thousand years air temperatures shifted by an average of 6 °C between mild and cold episodes, each switch taking about 50 years. Similar large and abrupt temperature oscillations have been seen from the end of the last ice age, and the GRIP variations were probably driven by the same mechanism — changes in the mode of circulation in the North Atlantic Ocean[3,4].

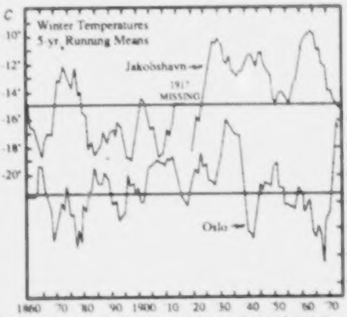
Taylor *et al.* have now fulfilled one important objective of the two-core strategy — their isotopic and layer-counting results confirm the amplitude and absolute timing of abrupt century-to-millennial scale climate changes during the last deglaciation and also the bistable nature of glacial climate. Where their report breaks new ground is in demonstrating that the longer-term climate shifts seen in earlier records are themselves marked by strong variations of less than ten years duration.

Their evidence comes from measurements of the core's electrical conductivity, a quantity that responds primarily to changing dust concentrations in the ice. Using 15 samples or more a year, Taylor *et al.* obtained a record of dustiness for the past 40,000 years with seasonal-to-annual resolution. Although the link between dust and climate is not fully understood, there is a clear relationship between cold climate and increased dust loading of the atmosphere (and of the ice) on timescales of millennia to centuries[5], most probably due to changes in the extent of source regions south of the former ice sheet in North America and air-mass turbulence and routeing over the northern Atlantic. The sensitivity of conductivity measurements to changes in actual dust concentration within the ice appears to be greatest during intervals of mild climate: during cold intervals the generally high dust loadings saturate the ice and further changes in dust content become undetectable. Despite this lack of sensitivity at the cold end of the climate spectrum, the records provide valuable insight into climate variability during periods of overall warmth. Most remarkable is the tendency of conductivity to reveal pronounced decade-long oscillations as climate shifted between longer-term modes.

For example, during the well-studied transition from the Younger Dryas cold period to the Holocene (the present interglacial), when average temperatures over the ice sheet rose by 7 °C in 50 years[6], the conductivity underwent three distinct order-of-magnitude oscillations (equating to fourfold changes in actual dust concentration[6]). Individual transitions spanned no more than five years each. A similar pattern is repeated at the beginning and end of each of the longer-term climate shifts of the last deglaciation. As it is improbable that the location or extent of dust sources in North America could change greatly on such short timescales, these oscillations are much more likely to be rooted in changes in air-mass trajectory or changes in soil moisture at the source region.

Taylor *et al.* refer to the oscillations at major climate transitions as flickers, implying that large-scale mode switches of the ocean–atmosphere system may have been briefly indecisive. Although pronounced decade-long oscillations of Atlantic circulation might occur as it settles into a new mode, the conductivity





Pressure patterns, as indicated by the height of the 700-millibar surface (in 30-m increments), for the severe North American and European winter of 1976–77 (*a*) compared with the average of winters from 1947–72 (*b*), showing the large difference in trajectory of geostrophic winds at 2,800 metres height near Greenland (after ref. 7). Associated changes in pressure at sea-level promote a tendency for winter temperatures to 'seesaw' between Greenland and northwest Europe, as evident in 5-year running averages of winter temperatures at Jakobshavn, Greenland, and Oslo, Norway (*c*, from ref. 8). Comparable changes in the past might account for the variations in dust content and conductivity in Greenland ice cores, but may also limit the extent to which regional temperature history can be generalized from the local one.

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record also displays marked variability throughout the mild parts of the ice age and its termination, and strong, persistent short-term oscillations of Atlantic circulation at these times seems unlikely (although some ocean models do produce such behaviour). Inasmuch as conductivity measurements indicate qualitatively similar variability during the early part of the Holocene and preceding mild intervals, it would appear worthwhile to look to the historical record of climate for evidence of interannual and decade-long oscillations between different preferred states of atmospheric and oceanic circulation.

One example that might produce changes in dustiness over Greenland is the North Atlantic Oscillation — a well-known tendency for negative correlation between severity of winters in Greenland and northwest Europe, and between sea-level pressure in the vicinity of Iceland and along a belt from the US east coast to the Mediterranean[7]. In addition to producing a dramatic 'seesaw' in winter temperatures between Greenland and northwest Europe[8], it is also marked by a significant shift in the orientation of winds aloft (see figure). Some of the most notable changes in wind-steering occur near Greenland. During the particularly severe winter in North America of 1976-77, when the seesaw tilted in the extreme, the pattern of pressure aloft was similar to the normal one but greatly exaggerated[9]. In addition to the obvious virtue of simplicity, this attribute of the North Atlantic Oscillation may have further attractions, because it suggests that this modern flicker could be amplitude-modulated in response to longer-term changes in boundary conditions.

Whatever the cause of the high-frequency changes at Summit, the results of Taylor *et al.* show clearly the capacity of the new ice cores to provide records of climate comparable to the instrumental record, but with the potential of spanning the last 200,000 years. At the bottom line, the interest is in what these may teach us about possible greenhouse warming. On the one hand, changes such as the North Atlantic Oscillation show that we will have to be very careful about generalizing from the local changes in Greenland. Longer-term variations reinforce this message: although the global mean temperature has risen by about 0.5 °C in the past few decades, temperatures around the North Atlantic and Greenland have fallen by the same amount[10]. Average winter temperatures on the coast of Greenland have repeatedly changed by up to 8 °C in the past century, putting the 7 °C change in mean temperature over the 50-year close of the Younger Dryas into a different perspective. Deciphering the new ice cores may not be easy: we can expect them to portray a complex response to climate change on a variety of timescales, from millennia to years, forced by a variety of local-, regional- and global-scale factors.

The geological record of such a diversity of variations in the climate poses climatologists and policy makers with an equally challenging puzzle — how long will we have to wait before we are convinced that we are seeing or not seeing a greenhouse signal? ☐

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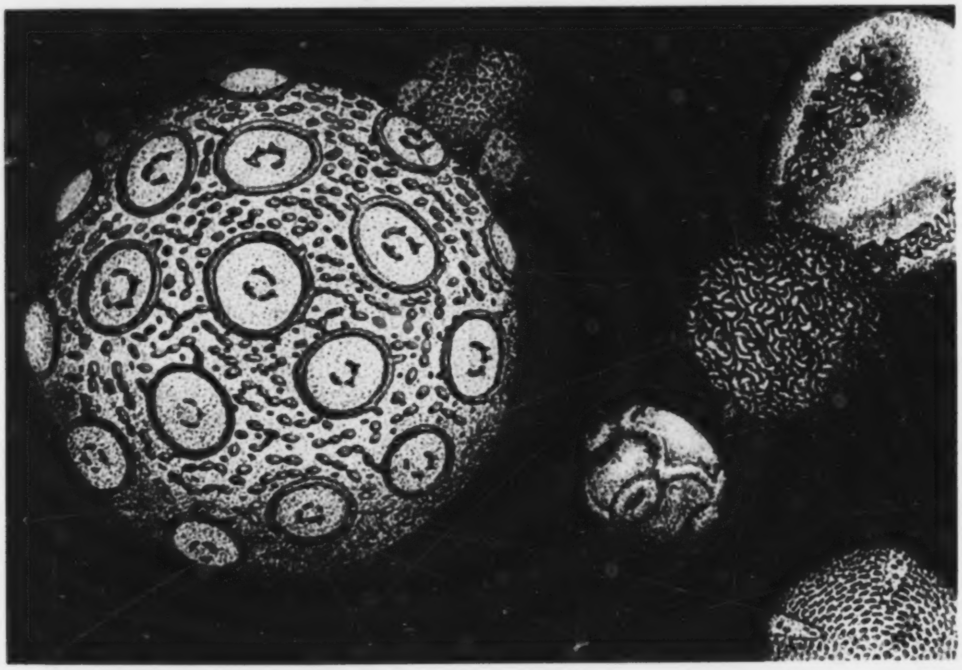

Pollen In Marine Cores:

by Linda E. Heusser

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To look in the oceans for direct evidence of past continental climates seems paradoxical. However, marine sediments contain far better terrestrial paleoclimate data than most continental deposits. On land, records of past climates found in glacial deposits, tree rings, or lakes are limited spatially and temporally, and prior to about 50,000 years ago accurate dating information is lacking. Although we are increasingly concerned with the relationship between the terrestrial biosphere and future global climate changes—the effect of increased carbon dioxide or a "nuclear winter"—our limited knowledge of past continental environments constrains predictions of future climates and environments.

To predict the future, we need to understand the past. The major source of global climate information lies in marine sediments. Cores from the world's oceans provide continuous, lengthy, chronologically-controlled climate-related signals, such as global ice volume and sea-surface temperatures. Deep sea cores from continental margins—the transition zone between oceanic and continental realms—also contain terrestrial climate signals: pollen derived from vegetation growing onshore.

Vegetation and Climate

The close relationship between the distribution of vegetation and climatic variables, observed by early

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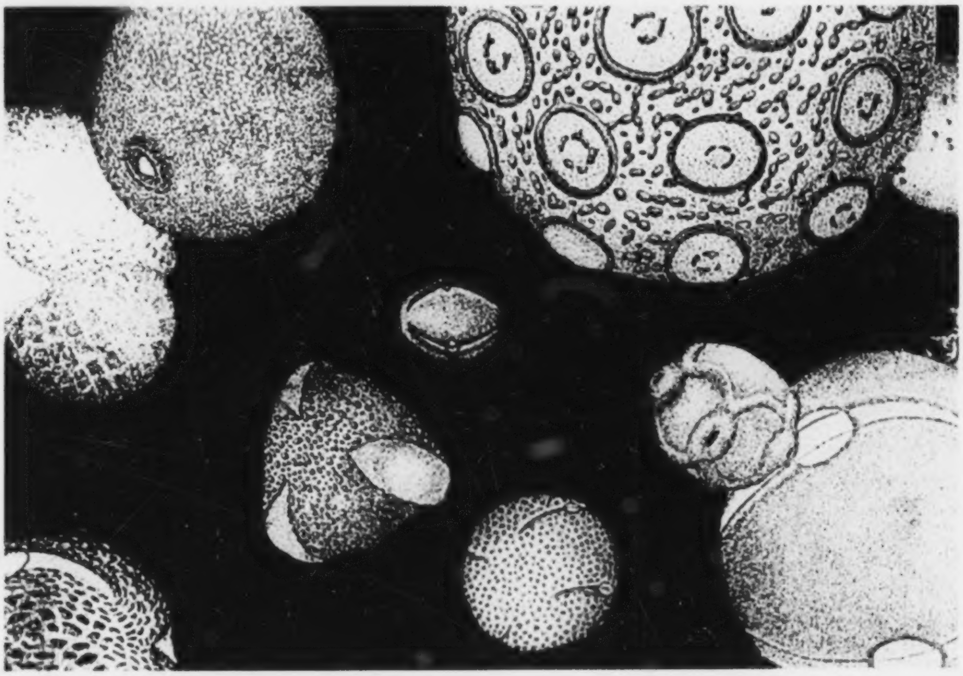

Evidence Of Past Climates

naturalists such as Charles Darwin and Alexander von Humboldt, forms the basis of using changes in plant abundance and distribution as a source of terrestrial paleoclimatic information, particularly during the last million years when evolution and extinction of plant species are minimal. Historically-documented changes in plant distribution, such as the disappearance of beech and chestnut trees from Rome in the first century, and variations in tree growth during the last thousand years, are closely related to temperature fluctuations. For longer vegetation records, the best source is pollen.

Pollen As a Vegetation and Climate Signal

As hay-fever sufferers know, pollen is ubiquitous and abundant. Deposited and preserved in lakes and bogs, these microscopic grains (Figure 1) document the nature of the surrounding vegetation. Fossil pollen preserved in lake deposits provide an estimate of environmental changes reflected by changes in plant communities around the lake. Quantitative climatic reconstructions are derived by calibrating spatial correlations between modern climate variables, such as temperature or precipitation, and pollen data sets, using the same

Above: Figure 1. Examples of terrestrial pollen typically incorporated into marine sediments. The diameter of these pollen grains is on the order of 20 to 120 microns.

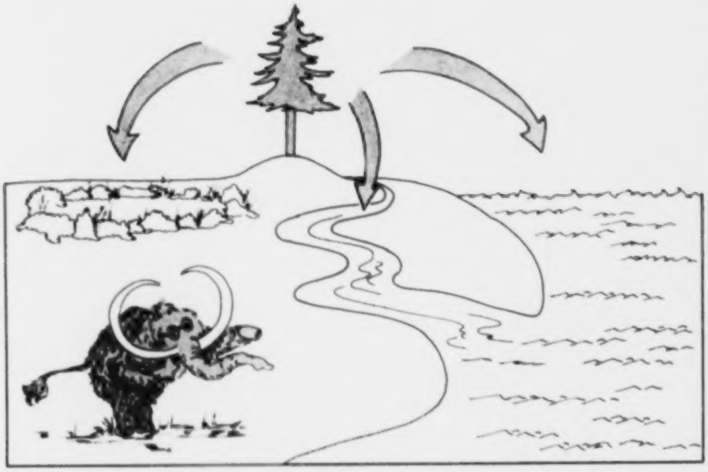

Figure 2. Most of the millions of pollen grains dispersed into the atmosphere are deposited within a short distance (less than a thousand meters) from their source, as symbolized by the left-hand arrow showing pollen from a lone pine tree dropping into a nearby lake. Pollen from vegetation growing immediately along the seacoast is carried by wind to the ocean, as shown by the right-hand arrow. Empirical studies show that fluvial transport (via streams and rivers), the middle arrow, carries most pollen to the ocean, where it is deposited along with the carbonate skeletons of marine microorganisms. Deep sea cores from the continental margins subsequently retrieve sediment containing both marine microorganisms and pollen—an unequaled source of terrestrial and marine paleoclimatic data.

multivariate statistical techniques pioneered by John Imbrie and N. G. Kipp to transform marine plankton data into quantitative estimates of sea-surface characteristics.

Most Quaternary* pollen records are less than 25,000 years old. Although these records provide detailed information about high-frequency climatic events since the end of the last major glaciation, long climatic signals, on the order of hundreds of thousands of years, are needed to understand the role of the terrestrial biosphere in the climate system. These signals are contained in ocean sediments.

Pollen in Marine Sediments

Pollen is abundant in marine sediments deposited on continental margins (the transition between the continents and the deep ocean basins). As on land, in ocean sediments pollen reflects the environmental parameters of the vegetation from which it is derived. Carried by wind and rivers to the ocean (Figure 2), pollen patterns in marine sediments generally correspond with regional vegetation patterns on land. In the northeast Pacific Ocean, distribution of coastal redwood pollen (*Sequoia sempervirens*) is basically restricted to sediments deposited off the redwood groves of northern California, and hemlock (*Tsuga*) pollen characterizes the sediments adjoining the magnificent hemlock-dominated conifer forests of coastal Washington and Oregon. In Japan, spruce (*Picea*) pollen dominates marine sediments surrounding the boreal forests of Hokkaido in the north. Pollen from the warm temperate forests of southern Japan, such as Japanese cedar (*Cryptomeria*) is prominent in sediments close offshore (Figure 3). This systematic relationship between pollen distribution in marine sediment and vegetation onshore is the basis for the calibration between marine pollen and continental environmental parameters.

Deep Sea Pollen Records

Deep sea pollen records provide a unique means of directly relating regional continental climate records with regional and global marine records because deposition of pollen grains in ocean muds corresponds with deposition of other components of the same sediment sample. Therefore, marine pollen records are correlated directly with the marine microfossil records from the same core. Thus, the pollen records are precisely related to global timescales developed from these marine microfossils.

The data from marine cores in different ocean basins differ both in length and in the climatic signal provided. Temperature and precipitation changes in northwestern Europe are correlated with global ice volume changes over a 50,000 year time span. Marine pollen in cores from the northeastern Pacific link the climatic history of northwestern North America to regional and global changes in the oceans and the ice sheets over the last 130,000 years. Paleoclimatic records of similar length from the Arabian Sea and the northwest Pacific document correlative continental and marine climatic fluctuations since the end of the previous ice age (140,000 years before present). These include changes in monsoonal wind intensity, precipitation, and temperature. Several examples follow.

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* The Geological Period extending from 1.6 million years before present to the present.

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Northeast Atlantic Ocean. Pollen records from a core taken in the northeast Atlantic Ocean about 100 kilometers off the Iberian Coast, and a core from northeastern France link western European climatic sequences from 125,000 to 75,000 years before present with global climate changes. French scientists conclude that during this time, the sequence of northwest European climatic events inferred from the pollen data generally agrees with changes in ice volume suggested by the oxygen isotope* curve.

During the last interglacial, ice volume apparently increased before climatic deterioration occurred in southwestern Europe. Full glacial conditions on land began after major ice-sheet accumulation. European climatic changes inferred from pollen signals agree with paleotemperature trends in the northeastern Atlantic Ocean. Both the maritime climates of western Europe and waters offshore remained warm during the initial phases of high-latitude ice-sheet accumulation at the beginning of the last glacial cycle.

Northeast Pacific Ocean. The first continuously-dated history of terrestrial climatic change in northwestern North America over the last 150,000 years is reconstructed from pollen and oxygen isotope analyses of cores taken in the northeast Pacific Ocean (Figure 4, page 68). Pollen profiles show nonglacial intervals of coastal lowland forest (typified by western hemlock) alternating with glacial intervals in which spruce and herbs are relatively more important. Temperatures, inferred from the ratio of western hemlock to spruce pollen, are highest during interglacials (isotope stage 1 and substage 5e) and lower during glacial events (isotope stages 2, 4, and 6).

Floral and faunal data from this deep sea core show similar terrestrial and marine climatic trends. Temperate forest pollen is highly correlated with the presence of subtropical and transition zone radiolarian faunas and with the absence of subpolar fauna. The herb-dominated pollen assemblage, prominent during glacial intervals, is correlated with the subpolar radiolarian assemblage found during intervals of increased dominance of marine subpolar conditions in the northeast Pacific Ocean.

Mathematical analysis of oxygen isotope, radiolarian (siliceous marine microfossils), and pollen data by Nicklas Pisias of Oregon State University indicates that most variations in these marine and land signals are found at periods around 41,000 years, the period of the orbital tilt cycle (see page 43). The occurrence of major changes in the vegetation of northwest North America at periods characteristic of orbitally-controlled insolation changes provides empirical evidence relating terrestrial climatic changes to orbital forcing.

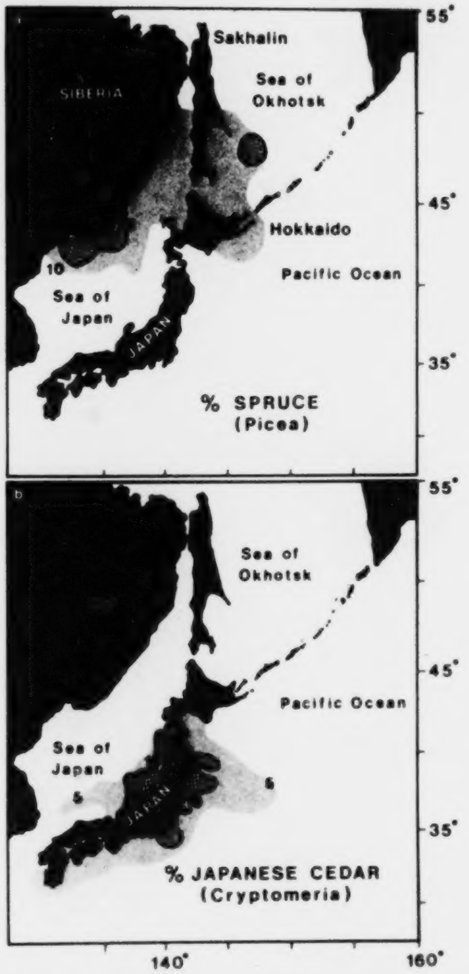

Figure 3. The geographic distribution of two diagnostic pollen genera in marine sediments of the northwest Pacific Ocean. Areas with significant amounts of pollen are shaded, with darker tones indicating the highest percentages of pollen. Spruce pollen (a) is most abundant near the spruce-dominated boreal forests of eastern Siberia, southern Sakhalin, and Hokkaido, the northernmost island of the Japanese archipelago. The highest quantities of Japanese cedar pollen (b), an endemic component of the warm temperature forests of Japan, are found in the marine sediments adjoining these forests in southern central Japan.

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* The ratio of oxygen-18 to oxygen-16 is commonly used in stratigraphic analysis. Oxygen consists mainly of oxygen-16 atoms, mixed with a relatively few oxygen-18 atoms. The proportion of the heavier oxygen-18 in the molecules of ocean water changes when the climate changes, since molecules containing the lighter atoms evaporate more readily. When they fall as snow, and become locked up in ice sheets, they leave the oceans relatively enriched in oxygen-18 — a sign of glacial conditions. These isotopes are recorded from the shell fossils of small marine animals present at the time. When extracted from a core sample of seabed sediment, a handful of such fossils is sufficient to determine the volume of the world's ice sheets at the time when they lived.

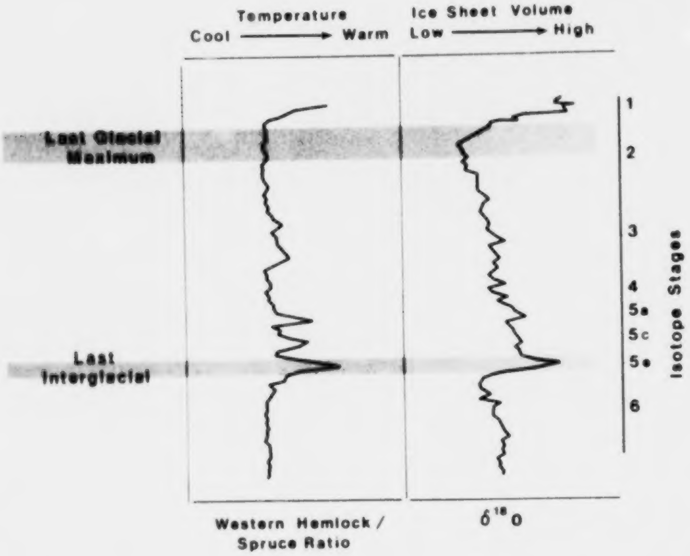

Figure 4. Climate signals from the last 150,000 years from northwest North America and the northeast Pacific Ocean, as obtained from a 16-meter deep sea core. Paleotemperature trends for coastal Washington and Oregon (left) are inferred from the ratio of western hemlock to spruce pollen (temperatures in western hemlock-dominated coastal forests are 1 to 2 degrees higher than in spruce-dominated forests). Global ice-sheet volume (right) is derived from changes in the oxygen isotope composition of the calcareous tests of foraminifera contained in the same sediment sample as the pollen

Cross-spectral analysis (mathematical comparison of signal frequency) shows that environmental changes on the Pacific coast of North America are not precisely synchronous with temperature changes in the North Pacific Ocean, or in global ice volume. Temperate conditions onshore are established after temperate conditions offshore, and changes in ice volume in the subarctic Pacific slightly precede sea-surface temperature changes.

Arabian Sea. American and French scientists (Warren Prell, Brown University, and Elise van Campo, University of Languedoc) reconstructed monsoonal wind intensity over the last 130,000 years from pollen and foraminifera assemblages in a core from the western Arabian Sea. Seasonal differences in the composition of aeolian (wind-borne) pollen in the Arabian Sea are related to the seasonal reversal of winds. Increased amounts of diagnostic pollen types from humid or montane areas of northeast Africa and southwest Arabia are associated with increased summer monsoonal winds and increased precipitation. Increases in the planktonic foraminifera (calcareous marine microfossils) signal, which is presently associated with temperature and nutrient evidence of summer coastal upwelling, are interpreted as evidence of stronger winds during the summer southwesterly monsoons.

Intensified summer southwest monsoons during interglacials are inferred from pollen and foraminifera. Both proxy climate indicators are coherent and in phase at 23,000 years, a period associated with the precessional cycle of the Earth's orbit (see page 43). Empirical evidence from Africa and the Arabian Sea show changes in the Indian summer monsoon associated with changes in seasonal solar radiation.

Northwest Pacific Ocean. The complexity of climatic change during the last 150,000 years is illustrated by terrestrial and marine signals from deep sea cores taken along a south–north transect in the northwest Pacific Ocean off the coast of Japan, in recent work done by J. Morley and myself at the Lamont-Doherty Geological Observatory of Columbia University. The first environmental records from the Pacific Coast of Japan covering the last interglacial-glacial cycle are represented by pollen assemblages (*Cryptomeria, Quercus, Pinus,* and *Picea*). Sediments in core RC14-99 record major changes between warm and cool temperate vegetation, 70,000 to 128,000 years ago. Warm temperate vegetation, characterized by the Japanese cedar (*Cryptomeria*) time series, expands during nonglacial intervals. Glacials, on the other hand, are characterized by expanded cool temperate oak (*Quercus*) forests, spruce (*Picea*) forests, and by the presence of an arctic/alpine indicator species (Figure 5, page 69). The last interglacial, clearly identified by the expansion of Japanese cedar between approximately 125,000 and 116,000 years before present is succeeded by two subsequent episodes of warm temperate forest expansion prior to the onset of full glacial conditions about 70,000 years ago.

Pollen profiles from a core, located near the warm-temperate vegetation of southernmost Japan, also document expanded Japanese cedar-dominated forests prior to 70,000 years ago. However, regional environments differed substantially during the last interglacial (oxygen isotope substage 5e). On the Pacific coast, Japanese cedar was strikingly unimportant in forests of southern Japan, while dominating forest communities in central Japan.

These climatic trends are summarized in Figure 6, page 70. The precipitation and temperature indices from the Pacific coast of Japan essentially reflect the importance of the standard Japanese paleoclimatic indicators of Japanese cedar, hemlock

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(*Tsuga*), and spruce. Summer temperature fluctuations inferred from pollen data in cores from 36 and 40 degrees North appear to correspond with regional Japanese paleoclimatic reconstructions, and with global ice volume changes and global estimates of sea-surface temperatures.

Temperature estimates from central Japan differ markedly from summer sea-surface temperatures offshore (at the core site) during the last interglacial, as do temperature estimates for southern Japan represented in the core from 28 degrees north. Like temperature, precipitation indicators from southern and central Japan show different trends in the interval between 140,000 and 120,000 years ago, suggesting drier, cooler conditions in the southeast as compared with the central coast.

Climatic signals from the vegetation of the Pacific coast of the Japanese archipelago over the last 150,000 years reflect global, regional, and local climatic variations with differing sensitivity. The transition or tension zone vegetation of central Japan appears closely tuned to global variations related to orbital forcing, as expressed in classic ice volume curves. Large-scale circulation changes associated with the Asian monsoon are suggested as important factors in climatic variations in southernmost Japan. In the last interglacial, for example, a stronger summer southeastern monsoon associated with northward movement of the atmospheric front would be consistent with our terrestrial temperature and precipitation reconstructions. Low glacial temperatures inferred from floral and faunal assemblages probably reflect intensified winter monsoons, as well as effects of Northern Hemisphere glaciation on regional atmospheric circulation.

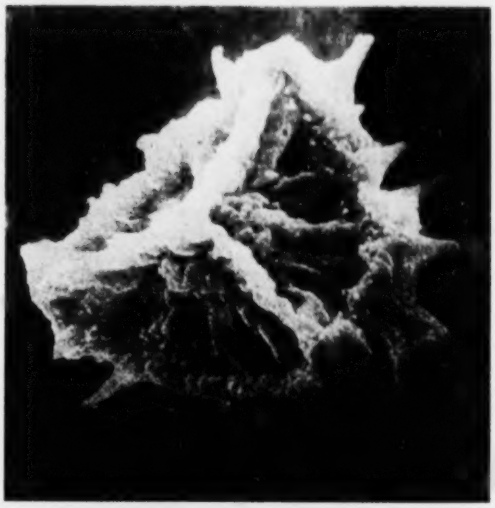

Figure 5. A scanning electron microphotograph (SEM) of a Japanese arctic/alpine indicator species, the spiked moss, Selaginella selaginoides. *The diameter of this pollen grain is about 50 microns.*

東海道
五拾三次之内
平塚
広重画

A woodblock landscape from a series of 53 stages on the royal road from Edo (Tokyo) to Kyoto (the former capital), by Ando Hiroshige (1797–1858). Pollen from Japanese trees, a record of climate, is archived in coastal marine sediments.

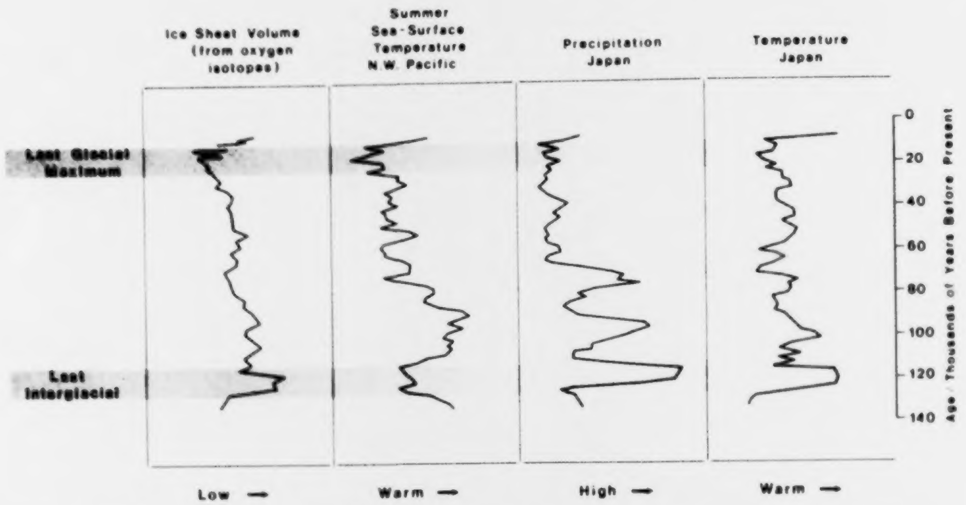

Figure 6. Northeast Asian paleoclimatic signals from the last 140,000 years. These climate records are derived from climatically-sensitive marine microfossils (selected foraminifera, radiolaria, and pollen) in cores taken east of Japan. Precipitation trends reflect the importance of Japanese cedar, and temperature trends reflect the prominence of spruce-dominated boreal forests in Japan. Except for the last interglacial when sea-surface temperatures were low, marine temperature fluctuations mirror changes in the vegetation and climate of north-central Japan.

Pollen Analysis Vital

Over the last 150,000 years, changes in broad-scale vegetation patterns, as documented by marine pollen, are correlated with changes in global temperature and precipitation. The frequency of these past fluctuations is associated with periodic changes in solar insolation. Future changes in components of the climate systems—variations in solar insolation or increased atmospheric carbon dioxide—will dramatically change the environment of the land we live on. How it will change is not precisely known. However, extending terrestrial climatic records in time and space is fundamental to understanding both the past and the future of the climate system.

Cores, particularly those on continental margins taken by the Ocean Drilling Program and by oceanographic institutions, such as the Lamont-Doherty Geological Observatory and the Woods Hole Oceanographic Institution, will extend records backward through time, and toward worldwide coverage. Pollen analysis from these cores will provide a worldwide terrestrial climate data bank. From the analyses of these data we may be able to better predict changes in both species composition and range of the vitally-important terrestrial flora as climate conditions on our planet continue to change.

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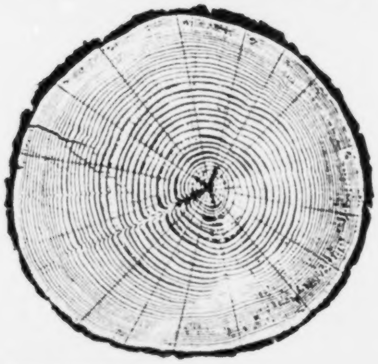
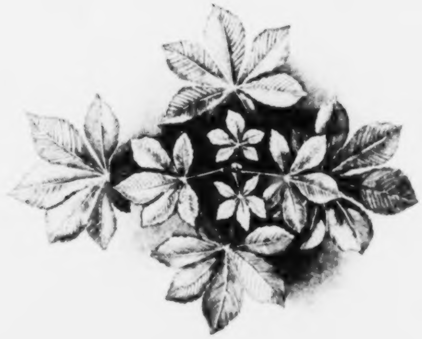
Logs of Straws: Dendrochronology





Background

Trees are some of nature's most accurate timekeepers. Their growth layers, appearing as rings in the cross section of the tree trunk, record evidence of floods, droughts, insect attacks, lightning strikes, and even earthquakes.

Tree growth depends on local conditions, which include the availability of water. Because the water cycle, or hydrologic cycle, is uneven—that is, the amount of water in the environment varies from year to year—scientists use tree-ring patterns to reconstruct regional patterns of drought and climatic change. This field of study, known as dendrochronology, was begun in the early 1900's by an American astronomer named Andrew Ellicott Douglass.

While working at an observatory in his native Arizona, Douglass began to collect pine trunk cross sections to study their annual growth rings. He thought there might be a connection between sunspot activity and drought. Such a connection could be established, he believed, through natural records of vegetation growth.

Douglass was not the first to notice that some growth rings in trees are thicker than others. In the climate where Douglass was working, the varying widths clearly resulted from varying amounts of rainfall. In drier growing seasons narrow rings were formed, and in growing seasons in which water was more plentiful, wide rings occurred.

In addition to correlating the narrow rings to periods of drought and, in turn, to sunspot records, Douglass had to establish the actual year each tree ring represented. Because absolute ages can be determined through dendrochronology, the science has since proven useful far beyond the narrow study to which Douglass applied it.

Computer analysis and other methods developed since Douglass' time have allowed scientists to better understand certain large-scale climatic changes that have occurred in past centuries. Likewise, highly localized analyses are possible. Archaeologists use tree rings to date timber from log cabins and Native American pueblos by matching the rings from the cut timbers of homes to rings in very old trees nearby. Matching these patterns can show the year when a tree was cut and, thus, reveal the age of a dwelling.

To determine whether changes now occurring in climate are part of the Earth's normal pattern or are induced by human activity, scientists rely on the history of climatic changes both locally and globally as revealed by tree rings, ice cores, pollen samples, and the fossil record. Computers are used to detect possible patterns and cycles from these many sources. In dendrochronology, large data bases allow scientists to compare the ring records of many trees and to construct maps of former regional climates. The evidence collected so far suggests that climatic change is simply a part of life on Earth. The extent to which human activity affects the way the global climate is changing now is not yet fully understood.

Activity (Allow 45-60 minutes)

In this activity straws will be used to simulate tree-ring core samples. Using the straws, students will work in groups to reconstruct a 50-year climatic history. Students will record this chronology on a 3-meter time line designed to highlight significant social, personal, and scientific events covering the same period.

Dendrochronologists seldom cut down a tree to analyze its rings. Instead, core samples are extracted using a borer that is screwed into the tree and pulled out, bringing with it a straw-size sample of wood about 4 millimeters in diameter. The hole in the tree is then sealed to prevent disease.

Materials

For each group of four students:

- One set of white straws marked with ring patterns (see illustration below). Markings can be produced with permanent black marker on paper or plastic straws
- One 3-meter strip of adding machine tape for each group
- Colored pencils for each group
- Colored markers for each group
- A notebook for recording results (optional)
- Reference material such as almanacs that provide students with the dates of social and scientific events over the last 4 decades

Prior to the activity the teacher should construct sets of straws similar to the set shown in the illustrations.

Group students in teams of four. The following information on the straw samples can be recorded on the blackboard or copied and handed out. Review with the students some of the tips on reading tree rings found in the boxed section.

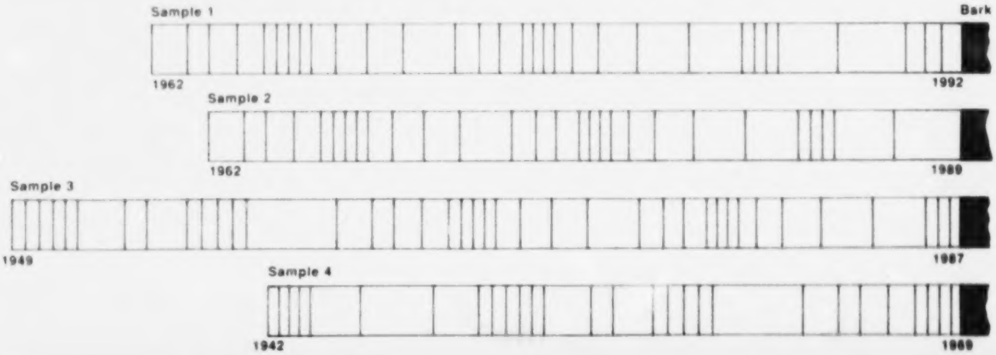
Reading Tree Rings

Core sample 1 is to be used as a standard against which to compare the others, because a bore date of 1992 has been established. Notice the varying patterns of ring widths in sample 1; look for similar patterns in other samples.

Core sample patterns are alternating dark and light lines. The darker lines of a core sample represent the end of a growing season. The light-toned space between the two darker lines represents one growing season.

Tree rings are formed from the center of the tree outward. The ring closest to the bark is the youngest and final growth ring. The ring closest to the center of the tree is the oldest growth ring. Neither the outer layer of bark nor the central pith layer of a sample is counted when determining the age of a sample.

Similar ring patterns are found between trees growing under the same conditions. The most obvious feature of these patterns is varying widths. Widening of a ring indicates good growing conditions, while narrowing indicates poor ones. Conditions can include climatic factors such as temperature and moisture as well as factors such as erosion, fire, landslides, etc.



Time and Cycles

Procedure

Imagine you have core samples from four trees:

Sample 1. From a living tree, July 1992, Pinetown Forest.

Sample 2. From a tree from the Pinetown Christmas Tree Farm.

Sample 3. From a log found near the main trail in Pinetown Forest.

Sample 4. From a barn beam removed from Pinetown Hollow.

1. Determine the age of each tree (how many years it had been growing) by counting the rings. Record your answers in your notebook or in the first column on the chart below.

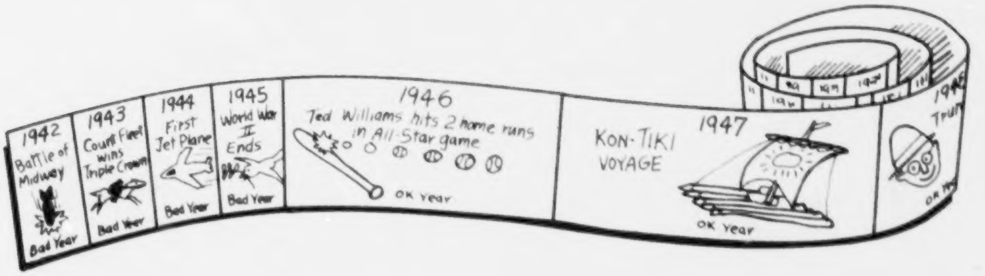
	Age of tree	Year tree was cut	Year growth began
Sample 1			
Sample 2			
Sample 3			
Sample 4			

2. Look for patterns in the rings. Patterns in this exercise match well, but actual ring patterns will vary among different species of trees. Once a ring pattern has been discovered, line up all the samples. Because you know that Sample 1 was cut in 1992, you can match the patterns of all the other samples and determine when all the other trees were cut or cored and also when they began to grow. Record this information in your notebook or fill in the chart above.

3. Make a time line. Spread out the adding machine tape. Beginning at the left end of the tape, record each year from the earliest year identified on the tree-ring samples through 1992. After the years are recorded on the strip, identify years that were good growing years for the trees in Pinetown, and years that were poor. Think of other events that might have happened during this time period such as your birthday, Presidential elections, important scientific discoveries, or record-setting sports achievements. Fill them in on the time line. You can color the time line and illustrate it with drawings, photographs, or newspaper clippings.

Questions

Which ring on each tree represents your birth year? What kind of growing season existed that year in Pinetown? In which years did droughts occur in Pinetown? Is there a pattern to the droughts? What buildings in your areas were built during the lifetime of these trees?


1942
Battle of Midway
Bad Year
1943
Count Fleet wins Triple Crown
Bad Year
1944
First Jet Plane
Bad Year
1945
World War II Ends
Bad Year
1946
Ted Williams hits 2 home runs in All-Star game
OK Year
KON-TIKI VOYAGE
1947
OK Year
OK Year

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Extensions

Measure the tree rings in the photograph on the back of the poster. Assume the tree was cut in 1992. How old is the tree? Can you determine good and bad years for growth?

Find and map the locations of some of the oldest known trees in your neighborhood. Sketch what you think a core from one of these trees might look like.

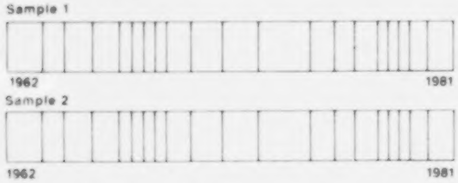
Contact your local forestry service or science museum and obtain some actual cross sections of trees that have been cut in your area. Use the techniques applied during this activity to "read the tree." If a tree has been cut in your neighborhood recently, look at the tree rings on the stump or ask if you can keep a small piece of the trunk.

Create some simulated core straws of your own for another group to analyze and report about.

For the Teacher

Aligning the samples

The following illustration shows how samples 1 and 2 can be aligned. Have the students align all four samples so that the patterns match, and determine the years when each tree was cut and when it began to grow. Have them count all the rings from the oldest samples as they are aligned with the younger samples to determine the total amount of time represented by the rings. Count aligned rings that appear on several samples only once.



Charts

The charts should be completed as follows:

	Age of tree	Year tree was cut	Year growth began
1	31	1992	1962
2	28	1989	1962
3	39	1987	1949
4	28	1969	1942

The total time covered by the tree rings is 50 years, from 1942 to 1992.

Answers to questions

The answers to some of the questions in the activities will depend on the individual class—for example, when they were born or when buildings in their area were built. In looking at the climate record as revealed in the tree rings, notice that there is a significant period of poor growing conditions in each of the four decades covered by the tree samples. This pattern, which can be graphed, is the type of pattern scientists might look for when studying climate change.

Classroom Resources

Angier, Natalie. Warming?—Tree rings say not yet. New York Times, Tuesday, December 1, 1992, p. C-1, C-4.

U.S. Geological Survey. 1991. Tree rings—timekeepers of the past. Reston, Virginia. USGS. 15 p.

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Reprinted with permission from *Global Climate - Past, Present, and Future*, S. Henderson, et al (Eds.), EPA Report No. EPA/600/R-93/126, pp. 77-89, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

How Do Scientists Analyze Greenhouse Gases and Global Temperature Data Over Time?

ACTIVITY 11

Lesson Focus:

What do scientists do with research data they collect?

Objective:

The student will be able to:

1. Comprehend how scientists gather data.
2. Organize raw data by charting data using charts and graphs.
3. Analyze the charts (graphs) and extend the analysis into the future.
4. Draw valid conclusions based on the research data.

Time:

2 Class Periods

Grade Level:

8–10

Key Concepts:

Scientific inquiry, data analysis, prediction

Definition of Terms:

Raw Data: Numbers that have not yet been organized or analyzed into meaningful results.

Graphs: Diagrams that represent the numeric differences in a variable in comparison with other variables.

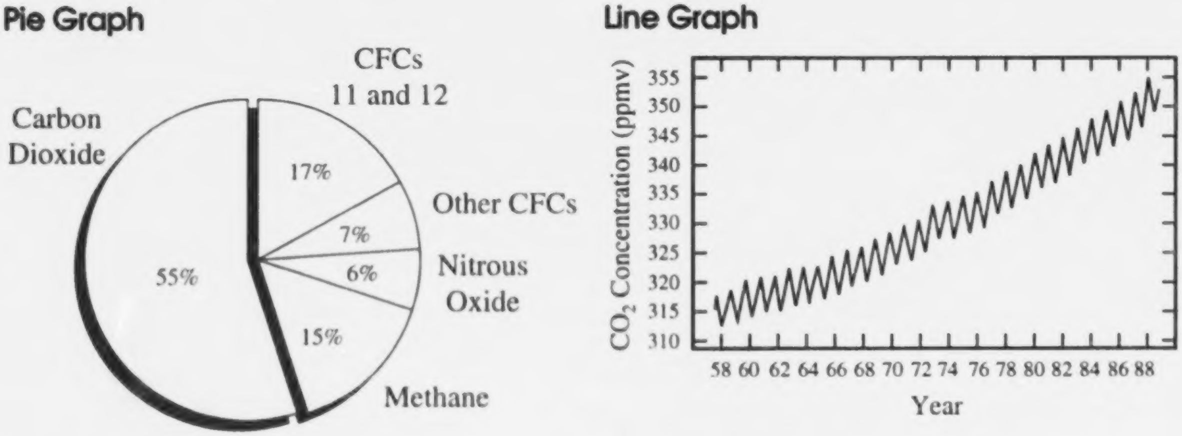
Background:

The data presented here were collected from basic research on atmospheric gases long before global climate change was a concern. Scientists interested in a particular gas either made or procured the right equipment, found a suitable place to study the gas, then spent several months setting up, calibrating, and checking the data. Eventually, the "raw data" accumulate and require analysis.

ACTIVITY 11

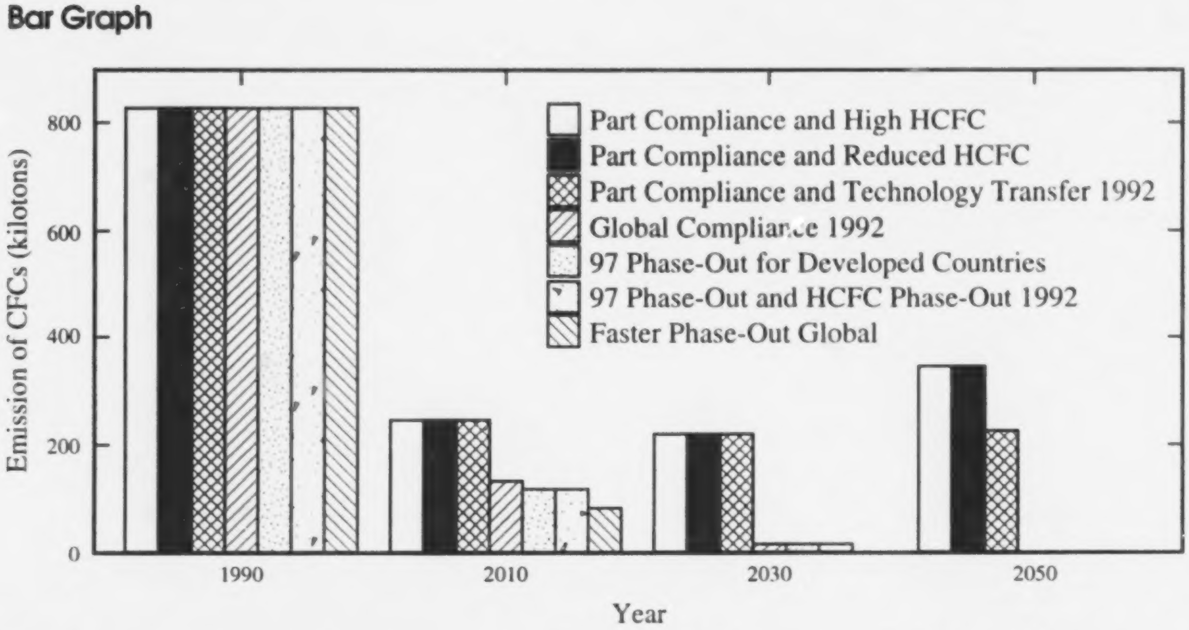
Just how the data are displayed is a question the scientist doing the work must deal with. The form – a chart, a line graph, a pie graph, or a histogram – is often personal preference.

Study the examples provided as possible ways to present the data (Figure 1). More detailed information on how the raw data were gathered is included later in this activity.



Pie Graph

Line Graph



Bar Graph

Figure 1. Examples of Different Ways to Display Data Graphically. Reproduced with permission from *Climate Change – The IPCC Scientific Assessment* (1990), World Meteorological Organization.

ACTIVITY 11

Activity:

Students will learn about changes that have occurred in some greenhouse gas levels and average annual temperatures within the recent past. The student will make one or more charts (graphs) of actual research data, find the trends, extend the trend into the future, and then draw a valid conclusion(s). The research data will include values for temperature change, carbon dioxide (CO_2), methane, nitrous oxide, and chlorofluorcarbons (CFCs) in the atmosphere. The extension to this activity provides information about the people involved in these scientific discoveries.

Materials:

- Raw data (attached)
- Pencil
- Graph paper
- Ruler

Procedure:

To familiarize students with scientific discoveries and the people behind them, have them read the Extensions to this exercise (*Monitoring Carbon Dioxide: How Science Is Done* and *The Vostok Ice Core*). Inform the students that they have been assigned a position in a research institution dealing with global issues. A research scientist has just given them some "raw data". Within the week there is a major international conference on this material and they need to analyze it by then. The data need to be presented and organized in a meaningful and useful way. Divide the class into small research teams.

1. Discuss where data come from, types of graphs available, what a trend is, and how to project a trend.
2. Have students simulate the role of a research scientists by telling them they have been assigned to this project.
3. Given the following data, have the students plot the values and make the curve for at least one graph. There are five different graphs, therefore make sure that all five are assigned so that each can be discussed.
4. Upon completion of the graph(s) have the students continue the trend of the curve for another 50 years.
5. Now have each student or student group develop a conclusion for their particular chart. Have students with the same graph get together and compare graphs for accuracy and conclusions.
6. Ask for a spokesperson for each type of graph to report a consensus view and a minority view for the interpretation of the graph.
7. Discuss the role of data analysis in scientific research. How do choices in displaying data affect communication?

Student Learning Portfolio:

1. A plotted graph of one of the atmospheric gases
2. A conclusion for the "raw data" provided to them

ACTIVITY 11

Raw Data:

Carbon Dioxide Concentrations (in ppmv*), Mauna Loa, Hawaii

Year	ppmv	Year	ppmv
1958	314.8	1974	330.4
1959	316.1	1975	331.0
1960	317.0	1976	332.1
1961	317.7	1977	333.6
1962	318.6	1978	335.2
1963	319.1	1979	336.5
1964	319.4	1980	338.4
1965	320.4	1981	339.5
1966	321.1	1982	340.8
1967	322.0	1983	342.8
1968	322.8	1984	344.3
1969	324.2	1985	345.7
1970	325.5	1986	346.9
1971	326.5	1987	348.6
1972	327.6	1988	351.2
1973	329.8		

*ppmv = Parts per million by volume.

Methane Gas Concentration

Atmospheric Greenhouse Gas Affected by Human Activities

Year	ppm*	Year	ppm*
1850	0.90	1975	1.45
1879	0.93	1976	1.47
1880	0.90	1977	1.50
1892	0.88	1978	1.52
1908	1.00	1979	1.55
1917	1.00	1980	1.56
1918	1.02	1981	1.58
1927	1.03	1982	1.60
1929	1.13	1983	1.60
1940	1.12	1984	1.61
1949	1.18	1985	1.62
1950	1.20	1986	1.63
1955	1.26	1987	1.65
1956	1.30	1988	1.67
1957	1.34	1989	1.69
1958	1.35	1990	1.72

*ppm = Parts per million.

Gaps in the record between 1958–1975.

ACTIVITY 11

CFC (chlorofluorocarbon)[1] Production

Atmospheric Greenhouse Gas Affected by Human Activities

Year	Amount[2]	Year	Amount
1955	100	1975	350
1957	120	1977	360
1959	140	1979	330
1961	150	1981	325
1963	150	1983	320
1965	200	1985	340
1967	225	1987	300
1969	290	1989	305
1971	320	1991	310
1973	375		

[1] CFCs include the manufactured gas combinations of chlorine, fluorine, and carbon. These gases were never present in the Earth's natural atmosphere until the 1930s.

[2] Values are in kilotons per year.

Nitrous Oxide

Atmospheric Greenhouse Gas Affected by Human Activities

Year	ppbv*	Year	ppbv*
1750	283.0	1880	289.5
1760	283.5	1890	290.0
1770	284.0	1900	291.0
1780	284.5	1910	292.0
1790	285.0	1920	292.5
1800	285.5	1930	293.0
1810	286.0	1940	294.0
1820	286.5	1950	295.0
1830	287.0	1960	297.0
1840	287.5	1970	299.0
1850	288.0	1980	305.0
1860	288.5	1990	310.0
1870	289.0		

*Values of N_2O concentration are in parts per billion by volume (ppbv).

ACTIVITY 11

Temperature Deviation Over Time[1]

Year	Temp. Deviation	Years BP[2]	Temp. Deviation	Years BP[2]	Temp. Deviation
1880	– 0.25	200	0.01	80,000	– 0.35
1885	– 0.27	1,000	0.01	85,000	– 0.30
1890	– 0.26	5,000	0.02	90,000	– 0.43
1895	– 0.29	10,000	0.03	95,000	– 0.52
1900	– 0.20	15,000	– 0.83	100,000	– 0.36
1905	– 0.38	20,000	– 0.90	105,000	– 0.40
1910	– 0.35	25,000	– 0.80	110,000	– 0.68
1915	– 0.33	30,000	– 0.82	115,000	– 0.64
1920	– 0.30	35,000	– 0.70	120,000	– 0.19
1925	– 0.15	40,000	– 0.60	125,000	– 0.09
1930	0.00	45,000	– 0.75	130,000	0.03
1935	– 0.10	50,000	– 0.60	135,000	0.10
1940	– 0.05	55,000	– 0.45	140,000	– 0.21
1945	0.05	60,000	– 0.80	145,000	– 0.75
1950	– 0.03	65,000	– 0.82	150,000	– 0.90
1955	– 0.01	70,000	– 0.70	155,000	– 0.82
1960	0.05	75,000	– 0.70	160,000	– 0.70
1965	– 0.05				
1970	0.00				
1975	– 0.05				
1980	0.15				
1985	0.18				
1990	0.21				

[1] For the purposes of this exercise, the mean average temperature from 1950 to 1980 is used as a baseline for comparative purposes. Note the 5-year average deviation values for the past 100 years, then the change to a 5,000-year spread for average deviation values. The values beyond 100 years were taken from ice core readings made by a USSR team of scientists working for years in the Vostok, Antarctic station.

[2] Years BP = years before present.

Extension

Monitoring Carbon Dioxide: How Science Is Done.[1]

Dr. Charles David Keeling

At the age of 26 and a new graduate of Northwestern University, Charles David Keeling went to work as a geochemist at California Institute of Technology in Pasadena. It was there that Keeling was to begin his life's work on little more than a bet.

Harold Brown, the man who had hired Keeling, made a comment that the amount of CO_2 dissolved in freshwater is always in balance with the amount of CO_2 in the air above the water. Hoping to spend more time out of doors, Keeling challenged Brown's assumption and asked to conduct an experiment to test Brown's ideas.

Keeling spent the following winter and spring developing a manometer to extract and measure CO_2 in parts per million. By the end of Keeling's first year at Caltech (1955) his manometer was ready. However, instead of beginning his tests along streams and lakes as the original study required, Keeling began measuring CO_2 levels on the grounds of Caltech. His first measurement registered 315 ppm CO_2.

Keeling continued taking measurements of CO_2 levels at Caltech every 4 hours for a 24-hour period. Keeling was on a roof at Caltech gathering his second set of measurements, when his wife Louise, gave birth to their first son, Drew. After Drew's birth, Keeling and his wife had similar evening schedules – every 4 hours Keeling would awaken to take the CO_2 measurements and Louise would awaken to tend to their new baby.

During the summer of 1955, Keeling, Louise and the infant Drew, camped at Big Sur, Yosemite, the Inyo and Cascade mountains, and the Olympic National Park, all the while Keeling filled flasks with air from these very different areas. After returning to the lab Keeling found an interesting pattern in the CO_2 levels of the flasks. He found that the CO_2 levels rose in the evening and dropped in the morning and afternoon.

Photosynthesis requires plants to take in CO_2 all day long to build sugars for growth, repair, reproduction. At the end of the day, however, the plants have all the food they need and must respire in order to use the CO_2. In doing so, plants release CO_2 back to the atmosphere.

The puzzle of Keeling's measurements was the mid-afternoon reading always measured 315 ppm – no matter where the measurement was taken. It seemed logical that the amount of CO_2 might fluctuate a bit due to shifting wind patterns, or changes in location, but that was not the case.

Later that year Keeling ventured back to eastern California and the Inyo mountains with more bottles to take more samples of the winter air. At 12,000 feet, every 4 hours Keeling took CO_2 samples for 5 days. The concentration of CO_2 in these bottles sat right at 315 ppm.

The reason? At that altitude the atmosphere has undergone significant mixing and is free of local influences of forests, cities, cars, industries. Keeling's findings suggested that the Earth's global average for CO_2 in 1955 was

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[1] Weiner, J. 1990. *The Next Hundred Years: Shaping the Fate of Our Living Earth.* New York, NY: Bantam Books.

315 ppm. So how was this related to Keeling's afternoon readings of 315 ppm elsewhere?

Although forests are influenced by any number of local conditions, generally, with the warming of the ground in the morning and early afternoon the air rises and is replaced by cooler air from higher in the sky. This is air that has been mixed so well that it represents the atmosphere of the entire planet.

Two weeks after Keeling had returned from the Inyo mountains, he was in Washington, DC, talking with scientists on what would be needed to monitor CO_2 levels on a global scale. The International Geophysical Year (IGY) was about to begin which would involve 18 months of global observations of earth air, water, fire, and ice. It was there that Keeling was offered a station at Mauna Loa, HI, to monitor CO_2.

Hawaii is the most isolated area in the world. The winds over it would represent a global average, at least for the northern atmosphere. The northern and southern atmospheres do not mix well. According to Keeling's previous measurements, it was expected that the first measurement from Mauna Loa would register 315 ppm. In fact, the first reading was 314 ppm.

In the first few months of the new Mauna Loa station the readings went up and down and then the station had power shortages. Once the station was finally up and running again the CO_2 measurements rose throughout the winter and then began to drop in the following spring. The first year's set of data when charted looked like a side view of a roller coaster. Keeling, however, believed he understood its message.

Having observed firsthand the daily cycle of CO_2, Keeling now believed he was observing an annual cycle. Here, photosynthesis begins in April, increases to a maximum in June, and continually declines through October. Respiration also peaks in June, however, it continues throughout the rest of the year as decomposition returns CO_2 to the atmosphere.

Since that first year of data on Mauna Loa several other stations have been set up in the northern and the southern hemispheres to record and monitor CO_2 levels throughout the world. The annual pattern that was observed in the first year continues to occur; however, the amounts of CO_2 are increasing.

The first decade of record keeping showed the CO_2 levels to be increasing at a rate of 1 ppm each year. After that, the data show that CO_2 levels are increasing at a faster pace – about 1.5 ppm per year.

Since Keeling began his measurements in 1955, average CO_2 levels have increased from 315 ppm to over 350 ppm. The trend indicates the amount of CO_2 in the Earth's atmosphere will likely continue its increase.

When compared to global average temperatures, both CO_2 levels and average temperatures are increasing. Is there a connection? Many believe there is, and as a result believe that the amount of CO_2 being pumped into the atmosphere from human activities must be reduced or serious social and environmental changes will ensue. For many others the verdict is still out on this issue and research is continuing at a feverish pace.

Keeling is still CO_2 dioxide and continues his work at Scripps Oceanographic Institute.

Extension

The Vostok Ice Core

Scientists have long sought ways of gathering more direct evidence for conditions on the ancient Earth than can be provided by theoretical ideas and the fossil record. One such method is the analysis of glacial ice cores from Antarctica and the Greenland Ice Cap. Snow that falls on the ice caps of Greenland and Antarctica usually does not melt. Instead, it slowly builds up, layer upon layer, for hundreds and thousands of years. As the snow accumulates and is compressed by the weight of the layers above it into ice, it traps minuscule bubbles of air. The surrounding ice prevents the air from escaping and/or mixing with air from the atmosphere above. As a result, the gas trapped in the ice is truly "fossil air", air from the atmosphere that existed at the time the original snow fell. By digging deep into the thick, persistent glaciers of Antarctica and Greenland, scientists can directly sample air from thousands of years ago.

Since the early 1970s, the Soviets and the French have collaborated on research at Vostok in Antarctica to drill and examine the deepest ice core ever studied. The Vostok core is over 2,000 meters long and samples ice layers deposited as long ago as 160,000 years. The core includes climatic information on the ice age that ended about 8,000 years ago and the ice age before it. The Vostok core is unique. It provides the most accurate CO$_2$ historical information thus far.

Consider the enormous effort involved in obtaining a core from a polar glacier. What were the mechanics involved? What would be some of the obvious hardships in undertaking a project such as this?

The Soviets perfected a thermal technique of drilling where the base of a 8m × 10 cm tube was electrically heated to penetrate the ice without damaging the core itself. In addition, it was not easy to keep the hole vertical. The drill had to descend carefully and excess water had to be quickly recovered to keep from refreezing (the average surface temperatures there were minus 55 °C) and distorting the sample. In the event the drill jammed for any length of time, the relentless movement of the Antarctic ice would deform the hole, destroying the core. The engineers had to be vigilant. It took 5 years (1980–1985) to extract the core. The hole left behind by this sample has been abandoned and another hole is soon to be started with drilling equipment that may probe even deeper than the original core, allowing even more ancient atmospheres to be sampled.

What the Vostok Core Revealed

Up until examination of this ice core, the connection between CO$_2$ and changes in the Earth's climate as a cause and effect relationship could not be substantially supported. One reason was earlier core samples only went back about 30,000 years and did not contain sufficient information to support CO$_2$ as a cause of climate change.

Studying the Vostok core has shown a positive relationship between increases in CO$_2$ and warm periods of the Earth's past, as well as correlations between ice ages and low amounts of atmospheric CO$_2$. Similar studies have shown that ice cores give reliable information on atmospheric conditions. As a result, the

Vostok CO_2 record provides evidence for a connection between the Earth's global climate system and the carbon cycle.

According to the researchers, the Vostok series provides direct support for an interaction between CO_2, orbital forcing (a term used to describe climate changes caused, or "forced", by changes in Earth's orbit – e.g., the Milankovitch theory*) and climatic changes. However, they are cautious about this interpretation because the core sample can provide only circumstantial evidence linking these factors. Data from the core cannot prove cause-and-effect relationships.

*The Milankovitch theory suggests that changes in the Earth's climate are related to variation in the Earth's orbital features. The Earth's orbital shape fluctuates at intervals of 90,000 years, the Earth's tilt on its axis changes at intervals of 41,000 years, and the Earth wobbles on its axis at intervals of 19,000 to 23,000 years. The fossil record indicates hat significant changes in the Earth's climate and types of organisms closely follow these cycles.

160,000-Year Record

The following information is extrapolated from a series of articles published in *Nature* (1987).

1. The CO_2 record seems to exhibit a cyclic change in periods of about 21,000 years. These cycles may be related to the 20,000 intervals described above in the Milankovitch theory. The researchers are very hesitant about this cycle, but it is interesting to note and discuss with your students.
2. The scientists took the ice core samples and crushed them under a vacuum, releasing the trapped gas which was then analyzed by a very sensitive gas sample chemical analyzer called a gas chromatograph. The scientists also measured deuterium (a heavy isotope of hydrogen) and an isotope of oxygen (^{18}O). Both of these are good indicators of temperature change; however, deuterium is a better indicator than is ^{18}O. The amounts of deuterium and CO_2 found in the ice core are directly related to the average global temperature at the time the gas was trapped in the ice.
3. The ice core covers the past 160,000 years and includes the Holocene (the last glacial period) the previous interglacial period, and the end of the penultimate (next to last) glaciation.
4. The CO_2 record exhibits the following:
   a. Two very large changes – one near the most recent part of the record, about 15,000 years ago, the other about 140,000 years ago.
   b. The high levels are comparable with the "pre-industrial" CO_2 levels that prevailed about 200 years ago. The low level ranges among the lowest values known in the geologic record of CO_2 over the last 10 million years.
   c. The two large changes in CO_2 correspond to the transitions between full glacial conditions (low CO_2) of the last and the penultimate glaciations, and the two major warm periods (high CO_2) of the record: The Holocene and the previous interglacial period.

References:

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Barnola, J.M., D. Raynaud, Y.S. Korothkevitch, and C. Louis. 1987. Vostok ice core provides 160,000-year record of atmospheric CO_2. *Nature* 329:408–414.

Genthon, C., J.M. Barnola, D. Raynaud, C. Lorius, J. Jouzel, N.I. Barkov, Y.S. Korothkevich, and V.M. Kotyakov. 1987. Vostok ice core: Climatic response to CO_2 and orbital forcing changes over the last climatic cycle. *Nature* 329:414–418.

Jouzel, J., C. Lousi, J.R. Petit, C. Genthon, N.I. Barkov, V.M. Kotyakov, and V.M. Petrov. 1987. Vostok ice core: A continuous isotope temperature record over the last climatic cycle (160,000 years). *Nature* 329:403–408. ❑

Notes:

How Do Scientists Analyze Greenhouse Gases and Global Temperature Data Over Time?

STUDENTGUIDE—ACTIVITY 11

Definition of Terms:

Raw Data: Numbers that have not yet been organized or analyzed into meaningful results.

Graphs : Diagrams that represent the numeric differences in a variable in comparison with other variables.

Activity:

You have been assigned a position in a research institution that addresses global issues. A research scientist has just given you some "raw data". Within the week there is a major international conference on this material and you must analyze it by then. The data need to be presented in a meaningful and useful way. Working with your team, organize, analyze, and present your data.

Materials:

- Raw data
- Pencil
- Graph paper
- Ruler

Procedure:

1. Plot the values and make a graph using the data your teacher provides.
2. Upon completion of the graph(s), continue the trend shown in your diagram for another 50 years (i.e., make a prediction on how you would expect the graph to look with 50 more years of data).
3. Develop a conclusion for your chart. If other students in your class are working with the same data, get together and compare graphs for accuracy and conclusions.
4. Share your findings with the class.❑

Reprinted with permission from *Global Climate - Past, Present, and Future,* S. Henderson, et al (Eds.), EPA Report No. EPA/600/R-93/126, pp. 25-38, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

What Information Do Paleobotanists Use to Study Ancient Climates?

ACTIVITY 5

Lesson Focus:

How do paleobotanists use ancient pollen to find out about Earth's climatic past?

Objective:

The student will be able to:

1. Distinguish the structural differences that are used for pollen classification.
2. Analyze pollen sample analogs to replicate the way that scientists gather paleo-data.
3. Interpret pollen sample analogs to replicate how scientists determine past climates.

Time:

2 class periods

Grade Level:

8–10

Key Concepts:

Past climates, vegetation changes, scientific investigation

Definitions of Terms:

Pollen grain: The microgametophyte of seed plants; each plant species has pollen grains with a shape unique to that species.

Paleobotanist: Scientists who study vegetation of the past.

Paleoclimatologist: Scientists who study past climates.

Palynologists: Scientists who study pollen.

Sediment: Is made up of organic (e.g., dead algae, dead fish, pollen) and mineral (e.g., soil erosion deposited from streams) materials that blanket the bottom of lakes, riverbeds, or oceans.

Background:

Evidence found in the geologic and plant fossil records indicates that the Earth's climate has been very different from today's in the distant past. There have, however, also been substantial climatic fluctuations within the last several centuries, too recently for the changes to be reflected in the fossil record. These more recent changes are important to understanding potential future climate change, and so scientists have developed methods to study the climate of the recent past. Although accurate human-recorded weather records cover only the last few decades, paleoclimatologists and paleobotantists have found ways of identifying the kinds of plants that grew in a given area in the past, and can infer from the plants what kind of climate must have prevailed at the time. Because plants are generally distributed across the landscape based on temperature and precipitation patterns, as these climatic factors changed, the plant communities also changed. Knowing the conditions the plants preferred, scientists can make general conclusions about the past climate.

One way paleobotanists can map plant distribution over time is by studying the pollen left in lake sediments by wind-pollinated plants that once grew in the lake's vicinity. Sediment in the bottom of lakes is ideal for determining pollen changes over time because sediments tend to be laid down in annual layers (much like trees grow annual rings). Each layer traps the pollen that sank into the lake, or was carried into it by stream flow that year. To look at the "pollen history" of the lake, scientists collect long cores of the lake sediment. Scientists obtain these samples with long tubes that are approximately 5 centimeters (cm) in diameter. A series of casings hold the hole open as the drilling proceeds. The cores can be 10 m long or longer, depending on how old the lake is and how much sediment has been deposited. The core that is removed is sampled every 10–20 cm and washed in solutions of very strong, corrosive chemicals such as potassium hydroxide, hydrochloric acid, and hydrogen fluoride. This harsh process removes the organic and mineral particles in the sample, except for the pollen, which is composed of some of the most chemically resistent organic compounds in nature. Microscope slides are made of the remaining pollen and are examined to count and identify the pollen grains. Because every plant species has a distinctive pollen morphology (called sculpturing), botanists can identify from which plant the pollen came.

Through pollen analysis, botanists can estimate the species composition of a lake area by comparing the relative amount of pollen each species contributes to the whole pollen sample. Carbon-14 dating of the lake sediment cores gives an approximate age of the sample.

Palynologists can infer the climate of the layer being studied by relating it to the current climatic preferences of the same plants. For example, a sediment layer with large amounts of western red cedar pollen can be inferred to have been deposited during a cool, wet climatic period, because those are the current conditions to which this species is adapted.

There are two reasons that scientists who study climate change are interested in past climates. First, by examining the pattern of plant changes over time, they can determine how long it took for plant species to migrate into or out of a given area due to natural processes of climate change. This information makes it easier to predict the speed with which plant communities might change in response to human-induced climate change. Second, by determining the kinds of plants that existed in an area when the climate was warmer than at present, the scientists can more accurately predict which plants will be most likely to thrive if the climate warms again.

Activity:

Students will examine pictures of pollen grains representing several different species, showing the structural differences that scientists use for identification. Students will analyze model soil samples with material mixed in to represent pollen grains. They will determine the type and amount of the "pollen" in the samples and, based on information provided to them, will determine the type of vegetation and the age of their samples and will make some conclusions about the likely climate at the time the pollen was shed.

Materials:

1. Pictures of several types of pollen (attached page 34) (*Note to Teacher:* An excellent example of different pollen types is found in the October 1984 issue of *National Geographic* on p. 492–493.)
2. One large graduated cylinder (1000 mL at least) for the "sediment" column
3. Five different types of "sediment" (any soil, sand, potting mixture, etc. that can be layered to show five distinct layers. You will need enough for the sediment column and the corresponding "samples")
4. Small, resealable plastic bags
5. Pie tins (one for each sediment sample)
6. Eleven different colors of paper "dots" (from a hole punch) to serve as pollen analogs
7. Key to the different "pollen" colors showing which colors represent which plants, and information about the climatic requirements for each plant species
8. Worksheets (provided)

Procedure:

Plants have pollen with unique morphology that can be used to identify them.

Ask the students to carefully examine the pictures of the different pollen types, noting the structural differences in each type. Discuss those differences, and how scientists can use those to identify the plants from which they were shed.

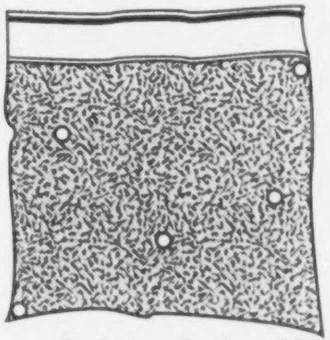
Analysis of pollen data gives evidence of paleoclimate.

Note to Teacher: The following exercise was developed based on actual pollen data collected from a lake in southwest Washington State. Other regions of the country may have similar pollen records available. The botany departments of local universities may be able to give you information on locally relevant pollen data that you can adapt to this exercise.

1. Layer five different kinds of soil (garden soil, sand, fine gravel, potting mixture, peat moss, vermiculite, perlite, or similar material) into the graduated cylinder so they form five distinct layers. This represents the sediment core with which the students will work. Label the layers with their respective ages as shown in Figure 1.
2. Choose eleven different colors of paper to represent the "pollen" grains. *Note to Teacher:* We have suggested colors (Tables 1 and 2); however, you can make your own

color choices. *To avoid confusion later, make certain you note any color changes on both Tables 1 and 2.*

3. Make the different color pollen grains by using the "dots" from a standard hole punch.
4. "Sediment" samples. Prepare one sample for each pair of students. It is important to make certain that all five layers of your sediment core are represented.
5. Fill the resealable plastic bags with approximately 100 mL of the same material representing a sediment layer in the core. For example, if you have sand representing Layer 1 in the sediment column, place 100 mL of sand in a plastic bag. If you chose a dark soil for Layer 2, place 100 mL of dark soil in a second plastic bag and so on until of 5 layers in the column have corresponding samples. Replicate until you have enough samples to distribute one to each pair of students.



6. Using Table 1 as a guide, place into each sample bag approximately 25 paper dots to represent the pollen found in that layer.
7. Begin by showing the sediment column and discussing the way that sediment is laid down in lakes, how it traps pollen, and how scientists obtain the lake sediment cores.
8. Hand out one sediment sample, a pie tin, and a worksheet to each pair of students. Explain that each sample contains "pollen" from the species prevalent at the time of deposition. Students should empty the contents of their sample into a pie tin. Their task is to sift through the sample to separate out the pollen from the sediment, determine from a key (Table 2) what species of plants are represented and what percentage of the total pollen comes from each species.
9. If more than one pair of students worked on any sediment layer, ask them to get together and come to a consensus on what plants they've found and the relative abundances. The worksheet can be used to keep track of the percentage of plants found in each layer. From the key (Table 2) have them come to a consensus on what the climate must have been like at the time of deposition.
10. Ask each group studying a sediment layer to report their conclusions to the class, then as a class build a consensus on the pattern of climate change represented by this sediment column. Students can complete their worksheets with data provided by students studying different sediment layers.
11. Once a class consensus has been reached, you may wish to share the interpretation of Dr. Cathy Whitlock, the paleoclimatologist that did the research this exercise is based on, with the class. The general conclusions of her paper and a map showing the area studied is provided in the attached summary "The Paleoclimate of Battle Ground Lake, Southern Puget Trough", Washington.

Note to Teacher: Ask the students to carefully replace the pollen in the sample bags. These samples can be used again.

Student Learning Portfolio:

1. Pollen grain drawings in log
2. Log entry on age/type of pollen in soil sample, and how it relates to climate
3. Completed worksheets

Extensions:

The extensions can be focused on further exploration of the role of pollen analysis in paleoclimate studies, on further student interest in the sculpturing of pollen itself, or on the role of pollen as an allergen. Possibilities are listed below.

1. Discuss some possible difficulties with obtaining sediment cores (tippy boats, bad weather, having the hole you've been drilling fill before you're done, etc.).
2. Discuss some reasons why most lake sediments can only tell you about vegetation hundreds or thousands of years ago (not millions). Possible answers–lakes aren't that long-lived, glaciers, mountain building, etc. will destroy lakes, sediment will eventually fill lakes completely.
3. Provide students with prepared pollen slides, or have students collect and mount their own pollen on slides for examination under a microscope. Ask them to sketch the different pollen types and produce their own identification key to pollen.

Figure 1. Model Sediment Column

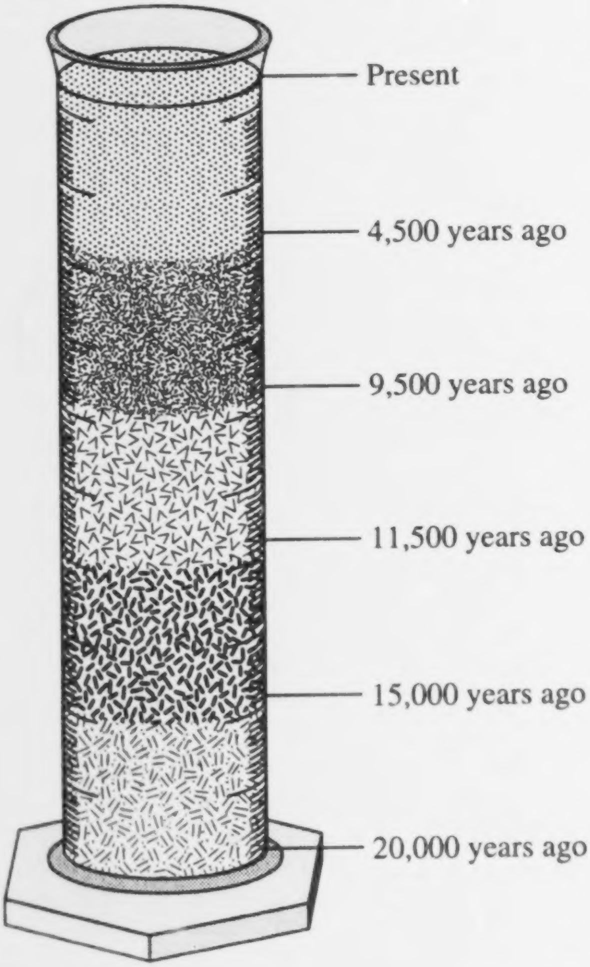


Table 1. Paper Dots and Amounts to Be Used to Make Up Each Sediment Sample (In the sediment age designations, ybp = years before present.)

Sediment Layer	Plant Species	Dot Color	Number of Dots	Percentage of Total
5 (4,500 ypb to present)	Cedar	Dark Blue	6	25%
	Hemlock	White	5	20%
	Douglas Fir	Brown	10	40%
	Alder	Red	4	15%
4 (4,500 ybp to 9,500 ybp)	Douglas Fir	Brown	3	10%
	Oak	Bright Yellow	3	10%
	Mixed Meadow Species	Light Yellow	19	80%
3 (9,500 ybp to 11,200 ybp)	Douglas Fir	Brown	7	30%
	Grand Fir	Pink	5	20%
	Alder	Red	13	50%
2 (11,200 ybp to 15,000 ybp)	Lodgepole Pine	Light Blue	7	30%
	Englemann Spruce	Light Green	3	15%
	Grand Fir	Pink	3	15%
	Grasses & Sedges	Dark Green	9	30%
	Alpine Sagebrush	Cream	3	10%
1 (15,000 ybp to 20,000 ybp)	Grasses & Sedges	Dark Green	15	60%
	Alpine Sagebrush	Cream	4	15%
	Lodgepole Pine	Light Blue	4	15%
	Englemann Spruce	Light Green	2	10%

Table 2. Pollen Key and Climatic Characteristics of the Vegetation

Dot Color	Species	Climatic Characteristics
White	Western Hemlock	Prinicipal dominant tree of many lowland, temperate sites. Requires very moist, temperate conditions for growth.
Brown	Douglas Fir	Broadly distributed throughout Pacific Northwest from moderately cool to warm sites. Grows best under temperate, somewhat moist conditions.
Dark green	Grasses & Sedges	This pollen from grasses and sedges typically found in very cool alpine/subalpine meadow sites characterized by very cool summers, harsh winters, and short growing seasons.
Red	Alder	Widespread throughout Northwest, often colonizing gravel bars or other poor soils, prefers abundant water and can grow in cool climates.
Pink	Grand Fir	Found at mid-elevations in Cascade mountains. Grows in cool climates, but not as cold tolerant as trees found at higher altitudes.
Light Green	Englemann Spruce	Found in cold, usually subalpine sites. It is an important timberline species in the Rocky Mountains.
Dark Blue	Western Red Cedar	Found only in temperate, very moist climates.
Light Blue	Lodgepole Pine	Found in areas of very cool climates typically growing on poor soils, often at high altitudes (above 3,500 feet) under the present climate.
Light Yellow	Mixed Meadow Species	This pollen is typical of a mixture of herbaceous plants common to warm-temperate meadowlands, such as may be found in the Willamette Valley in Oregon. Typically, these species grow in areas of warm summer temperatures and summer drought.
Dark Yellow	Oak	Found in warm-temperate sites characterized by dry, warm summers, such as can be found today from Oregon's Willamette Valley south into California.
Cream	Alpine Sagebrush	Woody, low-growing shrub related to the sagebrush of eastern Washington Oregon. Found only at high-altitude, cold sites.

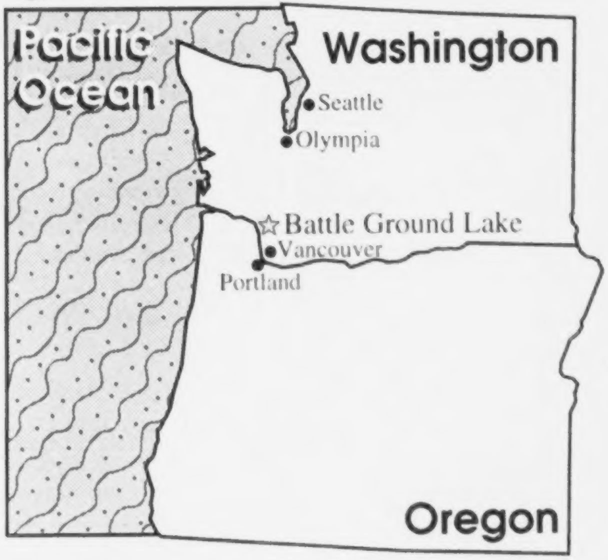
ACTIVITY 5

The Paleoclimate of Battle Ground Lake, Southern Puget Trough, Washington State:

The research site is located 30 km north of the Columbia River, in Clark County Washington, near the town of Battle Ground (Figure 2). The lake has been in existence for at least the last 20,000 years, and has continuously accumulated sediments through most of that time. Trapped in the sediments are pollen grains from the plants that grew in the general vicinity of the lake at the time the sediments were deposited. By examining the pollen in different layers of sediment from the bottom layer to the top, we can reconstruct the vegetation changes that have occurred in the area during the lake's existence. Because we know something about the climatic conditions that the plants needed to survive, we can use the vegetation data to reconstruct the past climate in the area for the entire 20,000 year period.

Many layers have been identified by paleoclimatologists. For simplicity sake, we will combine these into five major layers. The age of each layer has been established by radiocarbon dating and by reference to volcanic ash layers of known age from Mt. St. Helens and from the explosion of Mt. Mazama (now Crater Lake in Oregon).

Figure 2.



Layer#1: 20,000 –15,000 Years Before Present (ybp):

Glacial maximum, with nearly a vertical mile of ice over the site of Seattle, and the continental glaciers extending south of the present site of Olympia. An alpine glacier from Mt. St. Helens extended down the Lewis River Valley to within 30 km of the lake site. The lake area climate was cold, with a short growing season. The landscape resembled an arctic/alpine tundra, with the meadows dominated by alpine grasses/sedges, low woody shrubs, and scattered tree islands of cold-tolerant Engelmann spruce and lodgepole pine.

Layer #2: 15,000 –11,200 ybp:

Glaciers have begun to recede as the climate starts a warming trend. Although still cold in comparison to the present climate, the warming has progressed enough to cause the tundra vegetation to begin to be replaced by more extensive forests of lodgepole pine, Engelmann spruce, and grand fir in an open woodland setting. Further north in the northern and central Puget Lowland, many new areas have been opened up to plant colonization by the glacial recession, and lodgepole pine has invaded these new areas.

Layer #3: 11,200 –9,500 ybp:

The warming continues and the first occurrence of "modern", temperate coniferous forest is found in this period as Douglas-fir, alder, and grand fir dominate in forests not unlike those that occur today. The climate is similar to today's climate as well.

Layer #4: 9,500 –4,500 ybp:

The climate continues to warm with mild, moist winters and warm, dry summers predominating. The forests of the previous period (which needed cooler, moister conditions) disappear to be replaced by more drought-adapted mixed oak, Douglas fir, and dry meadowland community. Today such vegetation is typical of areas of the Willamette Valley of Oregon that have escaped cultivation.

Layer #5: 4,500 ybp –Present:

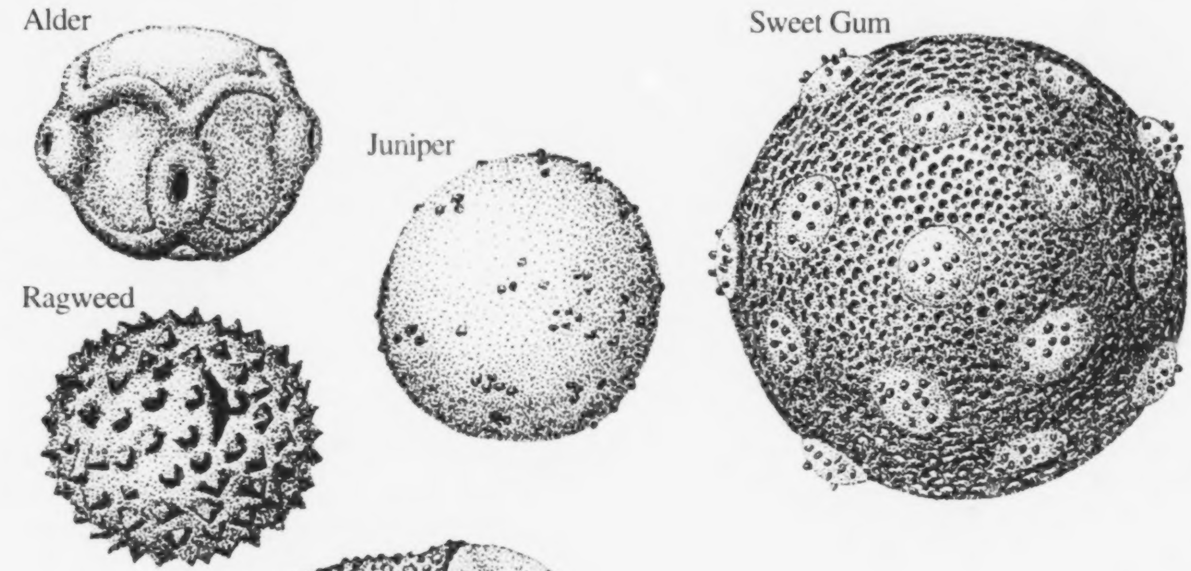
A cooler and moister period than the previous one. The dry-land vegetation is replaced by the extensive closed coniferous forests seen today, with hemlock and western red cedar dominating the areas of forest undisturbed by logging.

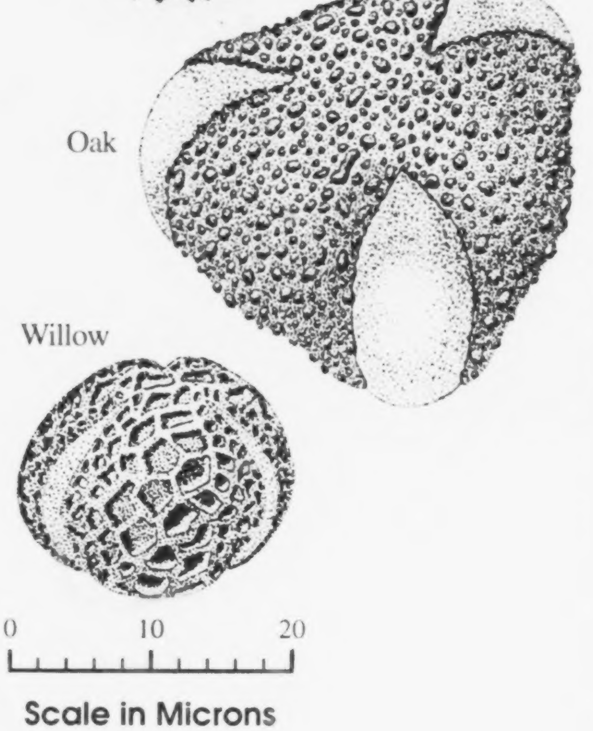
Reference:

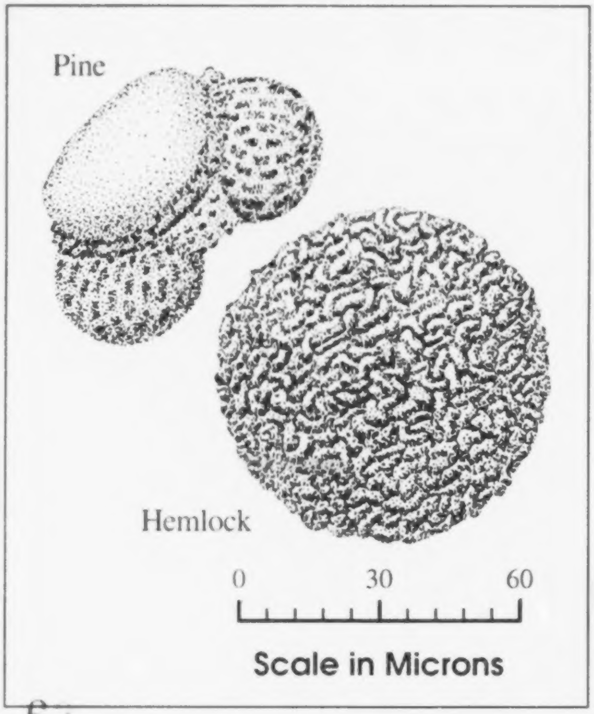
Barnosky, C. W. 1985. Late Quaternary vegetation near Battle Ground Lake, southern Puget Trough, Washington. *Geological Society of America Bull.* 96: 263–271.❑

ACTIVITY 5

Several Types of Pollen


Alder
Juniper
Sweet Gum
Ragweed


Oak
Willow
0
10
20
Scale in Microns


Pine
Hemlock
0
30
60
Scale in Microns

Pollen grain illustration courtesy of Allen M. Solomon, U.S. Environmental Protection Agency, Corvallis, Oregon 97333.

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What Information do Paleobotanists Use to Study Ancient Climates?

Student Guide—Activity 5

Definitions of Terms:

Pollen grain: The microgametophyte of seed plants; each plant species has pollen grains with a shape unique to that species.

Paleobotanist : Scientists who study vegetation of the past.

Paleoclimatologist : Scientists who study past climates.

Palynologists : Scientists who study pollen.

Sediment: Is made up of organic (e.g., dead algae, dead fish, pollen) and mineral (e.g., soil erosion deposited from streams) materials that blanket the bottom of lakes.

How do paleobotanists use ancient pollen to find out about Earth's climatic past?

Activity:

You will analyze sediment samples with other material mixed in to represent pollen grains, determine the type and amount of the "pollen" in the samples. From this information, you will determine the type of vegetation and the age of the samples and will present conclusions about the likely climate at the time the pollen was shed.

Materials:

1. Samples of sediment containing colored paper dots to represent pollen
2. Pie tin
3. Key to the different "pollen" colors showing which colors represent which plants, and information about the climatic requirements for each (Table 1, page 38)
4. Worksheet (your teacher will hand out)

Procedure:

The following exercise was developed based on actual pollen data collected from a lake in southwest Washington State.

1. Your teacher will first show you a model sediment core containing five separate layers, each laid down at a different time in the past. Pay attention to the color and texture of each layer to help you identify the samples from each layer you will be working with.
2. Each pair of students will be given a sediment sample, a pie tin, and a worksheet. Each sample contains "pollen" (actually colored paper dots representing pollen, with each color representing pollen from a different species of plant) from

plants that grew in the area at the time the sediment was deposited.

3. Your and your partner will separate out the pollen from the sediment. Empty the sediment into the pie tin. Sift and dig until you have found all of the pollen grains. Keep the pollen grains separated by color.
4. Use the pollen key (Table 1, page 38) to determine what species of plants are represented in your sample and what percentage of the total pollen comes from each species. Fill in the worksheet for the sediment layer you are working on.
5. Use the pollen key also to figure out what the climate was when your layer was deposited (use the climate information given with each species description to do this). Be sure to compare your sediment sample to those in the entire sediment core so that you know what level your sample is from and how old it is.
6. Compare your conclusions with others in your class who were assigned the same sediment layer. Do you all find the same plant types? Do you all agree on the climate that probably existed at the time?
7. With your class, discuss the species of plants found in each layer and the climate that probably existed at the time. Fill in the rest of your worksheet with the information provided by other students who studied different sediment layers. Can you determine what the overall pattern of climate change was during these last 20,000 years? Can you speculate about what might have caused the changes?❑

Notes:

Activity 5 Worksheet – Plant Species

Sediment Layer	Western Hemlock	Douglas Fir	Grasses and Sedges	Alder	Grand Fir	Englemann Spruce	Western Red Cedar	Lodgepole Pine	Mixed Meadow Species	Oak	Sagebrush
1											
2											
3											
4											
5											

Table 1. Pollen Key and Climatic Characteristics of the Vegetation

Dot Color	Species	Climatic Characteristics
White	Western Hemlock	Prinicipal dominant tree of many lowland, temperate sites. Requires very moist, temperate conditions for growth.
Brown	Douglas Fir	Broadly distributed throughout Pacific Northwest from moderately cool to warm sites. Grows best under temperate, somewhat moist conditions.
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Dark Yellow	Oak	Found in warm-temperate sites characterized by dry, warm summers, such as can be found today from Oregon's Willamette Valley south into California.
Cream	Alpine Sagebrush	Woody, low-growing shrub related to the sagebrush of eastern Washington Oregon. Found only at high-altitude, cold sites.

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VOLCANIC ERUPTIONS AND GLOBAL CLIMATE CHANGE

BEFORE

AFTER

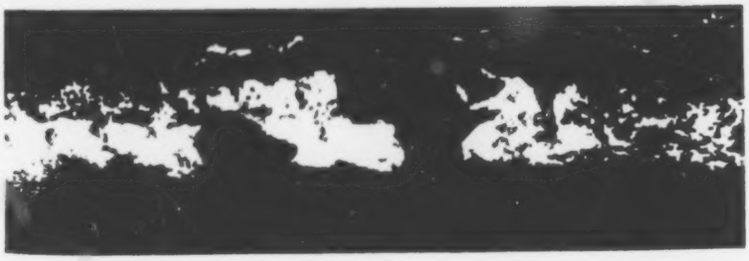

Figure 1. - **These images from a U.S. National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellite illustrate the aerosol cloud thrown into the stratosphere by the eruption in June of 1991 of Mt. Pinatubo in the Philippines. As the cloud became more evenly distributed through the stratosphere during the Northern Hemisphere winter, it depressed the mean global temperature by some 0.5°C. (Source: NOAA, 1991.)**

When Benjamin Franklin visited Europe in the summer of 1783 he noticed a "dry fog" or haze. He also observed the following winter that Europe was abnormally cold. He suggested that these abnormal weather conditions were the result of volcanic activity. Years later it was discovered that the Laki Volcano in Iceland had erupted in 1783. In 1816, Europe experienced an unusually cool summer and that year was nicknamed the "Year without a Summer." One year before this cool summer, a very powerful eruption occurred on Mt. Tambora in Indonesia.

Activities for the Changing Earth System: funded by a grant from the National Science Foundation and with support from The Ohio State University.

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In another instance strange colors and halos around the sun and moon were observed in 1883, along with vivid sunrises and sunsets. These very memorable occurrences followed the most explosive eruption in recorded history, Krakatau in Indonesia, July of 1883. The Krakatau eruption had other global consequences. A loss of 20 - 30% of direct solar radiation for three years followed this explosive event.

The eruption of El Chichon in 1982 in Mexico gave climatologists strong evidence of the potential impact of volcanic activity on global climate change. This eruption, like Krakatau, ejected great quantities of dust, ash, carbon dioxide, and sulfur dioxide high into the stratosphere (Figure 2). Most recently, Mt. Pinatubo, located in the Philippines, erupted several times in June of 1991. This eruption caused spectacular sunrises and sunsets around the world. By mid 1992 it had thrown out twice as much volcanic dust and aerosols as El Chichon.

Large volcanic eruptions cause short-term cooling of the climate. If the climate were in a warming trend at the time of the eruption, the eruption might merely slow the process and no cooling effect might be detectable.

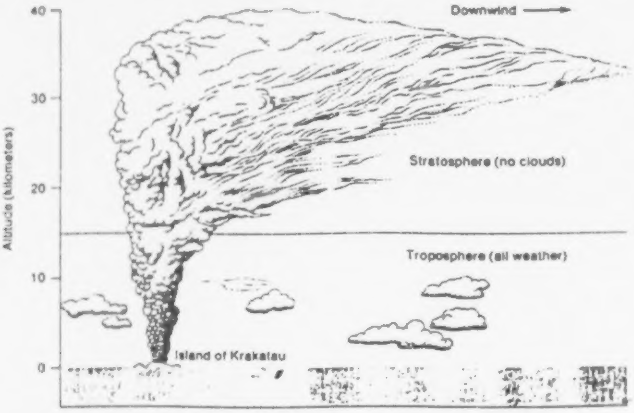

Figure 2. - The Krakatau cloud of 1883 was injected high into the stratosphere. (Source: Decker and Decker, *Volcanoes*, 1989.)

Once all of the volcanic dust and aerosols are injected high into the atmosphere, upper level winds and global pressure systems can circulate this material around the Earth. Volcanic aerosols, in particular sulfur dioxide, can block incoming solar radiation and reduce global surface temperatures for up to two to four years following the eruption (Figure 3). The concepts studied in these activities include: *volcanic emissions; aerosols; global temperature change and acid precipitation.*

Objectives: Upon completion of this activity, students will be able to:

1) locate major volcanoes around the world using latitude and longitude (Activity A).
2) explain how the latitudinal location of a volcanic eruption may affect global climate conditions (Activity A).

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3) use the Volcanic Explosivity Index (V.E.I.) to predict the potential of a volcanic eruption to affect global climate change (Activity A).
4) describe the effect of acid precipitation from volcanoes on various materials and environments (Activity B).
5) examine the influence of wind currents on aerosol distribution and its consequences (Activity B).

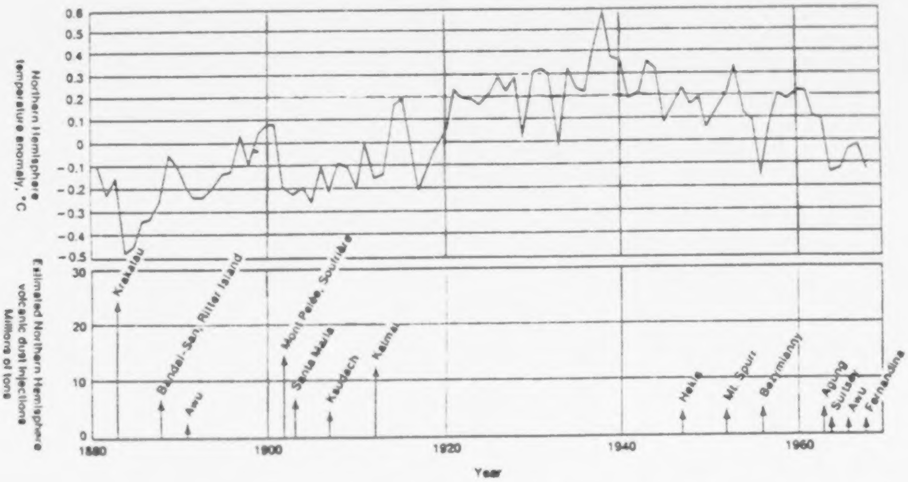

Figure 3. - Graph of average temperature variations after major volcanic eruptions. (Source: Oliver, *Journal of Applied Meteorology*, 1976.)

Earth Systems Understanding (ESUs): This activity focuses on ESUs 3 and 4. However, the following ESUs are covered in the Extensions — 1, 5, 6 and 7. Refer to the Framework for ESE for a detailed description of these understandings.

Activity A: Where and when have recent volcanic eruptions occurred?

Volcanic eruptions differ. Some eruptions produce great quantities of dust and aerosols, while others produce just lava. As a result, not every volcanic eruption can produce significant global climate changes. Some of the significant characteristics needed for an eruption to affect global climate conditions include the latitude of the volcano, the season of the year it erupted, the height of the eruption, and the type and quantity of gases produced.

Materials: large physical wall map of the world; a blank 8 1/2" X 11" map of the world with latitude and longitude lines; library resources or a computer data base for information on volcanic eruptions (see reference list at the end of the activities).

Procedure:

1) Using Table 1 and the blank 8 1/2" X 11" map of the world, locate by latitude and longitude each of the volcanoes listed in the table.

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2) Label each volcano with its name, its elevation above sea level, and the date of the eruption on the map.

3) When you have completed locating the volcanoes you will notice the lack of volcanoes in the Southern Hemisphere. What possible explanation is there for this observation?

4) Climatologists have theorized that only low latitudinal volcanic eruptions, between 20° N and 20° S, can significantly affect global climate conditions. What is the possible basis for this theory?

[The volcanoes listed in Table 1 were selected at random. The intent is to give an even distribution of V.E.I. between the values of 4 and 6.]

Location	Elev. (m)	Lat.	Long.	Date	V.E.I.
Krakatau, Indonesia	0813	6.1S	105.42E	08 1883	6
Pelee, West Indies	1397	14.8 N	61.17 W	05 1902	4
Santa Maria, Guatemala	3772	14.8 N	91.55W	10 1902	6
Ksudach, Kamchatka	1079	51.8 N	157.52 E	03 1907	5
Katmai, Alaska	0841	58.3 N	155.16 W	06 1912	6
Katla, Iceland	1363	63.6 N	19.03 W	10 1918	4
Komaga-take, Japan	1140	42.7 N	140.68 E	06 1929	4
Agung, Indonesia	3142	8.3 S	115.51 E	03 1963	4
Taal, Philippines	0400	14.0 N	121.00 E	09 1965	5
Mt. St. Helens, U.S.A.	2549	46.2 N	122.18 W	05 1980	5
El Chichon, Mexico	1060	17.3 N	93.2 W	03 1982	5

Table 1. - Data from eleven major explosive volcanic eruptions.

Another significant variable affecting the impact of an eruption on global climate change is the power of the volcanic eruption and the direction of the blast. Some volcanic eruptions are extremely explosive and can inject material high into the stratosphere. Volcanologists have developed a Volcanic Explosivity Index (V.E.I.) to compare eruptions. Volcanoes are rated from 0 to 8, where 0 is the least explosive and 8 the most explosive.

5) Arrange the data provided in Table 1 in different ways. Sort the volcanoes by their V.E.I., arrange by latitude and determine if a correlation exists; sort by V.E.I., arrange by longitude and investigate for any correlation; sort by V.E.I., arrange by date and examine any correlation, etc. Continue this process until all the variables have been examined in relation to each other.

[If computers are available to the students, they should produce a database of the information provided in Table 1. The arrangement of the data should follow that outlined above.]

6) From the information in Table 1 (and the database), which volcanoes could have the greatest effect on global surface temperatures?

7) Many climatologists have criticized the V.E.I. because it does not accurately assess some of the important aspects of a volcanic eruption. Considering global change, what characteristics of an eruption does the V.E.I. not take into account?

Activity B: Do volcanic eruptions have an impact on global climate and atmospheric conditions?

Volcanic eruptions can affect global surface temperatures by producing sulfur dioxide gas. Sulfate particles can backscatter incoming radiation warming the stratosphere, thus reducing the amount of incoming radiation effectively cooling the troposphere. (Figure 3 illustrates the cooling effect of volcanic particulates from major eruptions.) Sulfates eventually precipitate out of the stratosphere. An excellent record of sulfate concentrations is found in ice cores from the Antarctic and Greenland ice sheets. These sulfate ice core records are a source of information to help reconstruct past explosive volcanic eruptions and their effect on global climate change.

When great quantities of sulfur dioxide are released by a large volcanic eruption, the gas will oxidize in the stratosphere and combine with water vapor to produce tiny particles of sulfuric acid (Figure 4). This process takes about one month and the particles have a lifetime of three years. The chemical reaction is as follows:

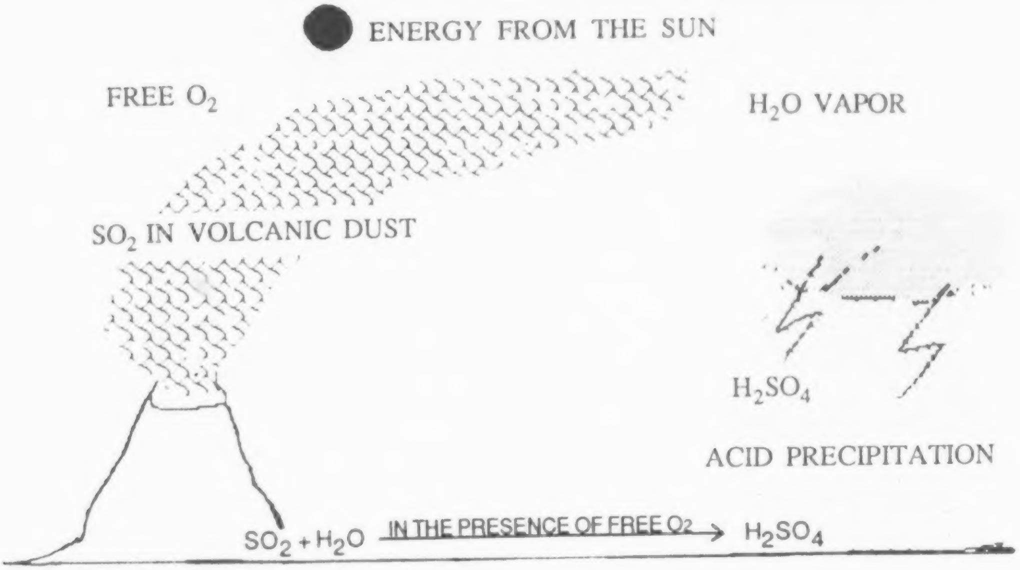


Figure 4. - A diagrammatic representation of the chemical process that occurs when SO_2 is oxidized (in the presence of free O_2) and combines with H_2O vapor to produce H_2SO_4. Energy for this chemical process comes from the sun.

During the time that this process occurs, the sulfur dioxide particles are carried on wind currents, with the result that sulfuric acid precipitation may fall in regions quite distant from the site of the eruption. This creates an additional problem in the form of acid precipitation and its influence on different environments. In this activity, the students will test various materials with a sulfuric acid solution, recording and analyzing the results. Discussion can relate these results to volcanic eruptions.

Materials: copy of Figure 1; 4 ml of 1 molar sulfuric acid to prepare 2 liters of acid rain solution pH 3 - TO BE PREPARED BY THE TEACHER; data sheet; various materials to be tested such as different types of rocks (limestone, sandstone, basalt, etc.) soil, metals, water, etc.; filter papers; 1 clear plastic cup 9 oz. capacity; rubber bands; some Universal Indicator solution; some distilled water; droppers.

Procedure:

1) Divide the class into groups, with at least 4 students per group. Each group should receive a set of materials to conduct the experiments.

2) **REMIND STUDENTS OF THE APPROPRIATE SAFETY CONSIDERATIONS.** A few drops of acidic solution is placed on the surface of the different rocks and metals. Have students describe the results on the data sheet.
   - Did all the materials react the same? If so, why? If not, why not?
   - What influence would this have on stone buildings? Are there any commercial uses for this effect? What are they?
   - What influence would this have on metal structures? Are there any commercial uses for this effect? What are they?

3) The students should test the pH of water from natural sources, like streams, rivers, ponds and lakes, with the Universal indicator. Each group should test water from a different source in this manner.
   - Place 4 ml of indicator in the plastic cup. **(REMIND STUDENTS OF THE APPROPRIATE SAFETY CONSIDERATIONS).** Add 10 ml of the water samples to the cup. Each group should record the results on the data sheet. Each group should inform the remainder of the class of the results.
   - Now add 10 ml of the acid rain solution to the water. Note the results for each water sample. How has the pH value changed?
   - What impact would this pH change have on the organisms that live in this water? How would it impact a food chain based on these aquatic organisms?

4) The students then should test soil samples from different sources as follows:
   - Place the cup on white paper. Place some soil on the filter paper. Add three drops of Universal Indicator to the cup. Suspend the filter paper containing the soil over the cup and secure it with the rubber band. Pour 5 ml of distilled water onto the soil sample, allowing the water to flow through the soil and drip into the cup. Record the resulting pH of the liquid in the cup.

- Repeat this procedure with a new soil sample and 5 ml of acid rain solution. Record the resulting pH of the liquid in the cup.

  [All results should be shared with the class and recorded on the data sheets.]

- What impact does the acid rain have on the soil samples? What impact would acid rain have on the microorganisms in the soil? What influence would acid precipitation have on the vegetation rooted in this soil?
- What do you think would happen to the pH of water runoff from soil that now experiences acid precipitation? This water runoff would eventually reach an aquatic environment. List the possible impacts this water may have on this type of environment.

5) Examine Figure 1, and explain how the Mt. Pinatubo eruption might influence environments near the eruption site through acidic precipitation. What impact could acidic precipitation from this eruption have on other countries?

- What type of data would be most useful to climatologists in order to prove that this volcanic eruption could affect global climate conditions? Analyzing the data from Table 1, predict which volcanoes would have the most/least impact on the global climate. Why? Correlate your predictions with the data in Figure 3.

- Is there any way this evidence could be masked or hidden by other global climate events? In the short term, how might volcanoes influence climate? How could this impact on the climate and weather affect the public's understanding of global warming/change?

6) What are some additional sources of SO_2 and other aerosols? What impact would these have in comparison to volcanic emissions? Which are easier to control? Why?

Evaluation:

On completion of this activity, the groups should create a concept map, showing how the volcanic eruption may influence other environments on a global scale. The various concept maps should be discussed and a class concept map may be produced by the teacher on the chalkboard.

[Refer to page 187 for an example of a concept map on deforestation.]

Extensions:

1) Volcanoes have been represented in many ways throughout the development of human cultures. Some believed volcanic eruptions signaled a god's anger or displeasure with people. Some cultures even sacrificed people to the volcanoes in an attempt to appease them. Vivid sunrises and sunsets have resulted in local areas and globally for many years, following an eruption. Select one of these points and investigate how different cultures have represented or recorded volcanoes and their activity. How do we record such events today?

2) Describe how and why volcanoes occur and their role in the evolution of this planet. How have scientists helped us to understand volcanoes? Investigate the scientists who first helped us recognize volcanoes as part of the Earth's evolutionary process, and how recent technology has aided us in appreciating the processes involved.

3) Have volcanoes occurred on other planets in our solar system? If so, on what planet(s) have they occurred? Do they still exist? How can we improve our knowledge of the volcanic processes by examining other planets? Could they help us unlock further knowledge concerning the formation of this planet? How? Give evidence to support your answers.

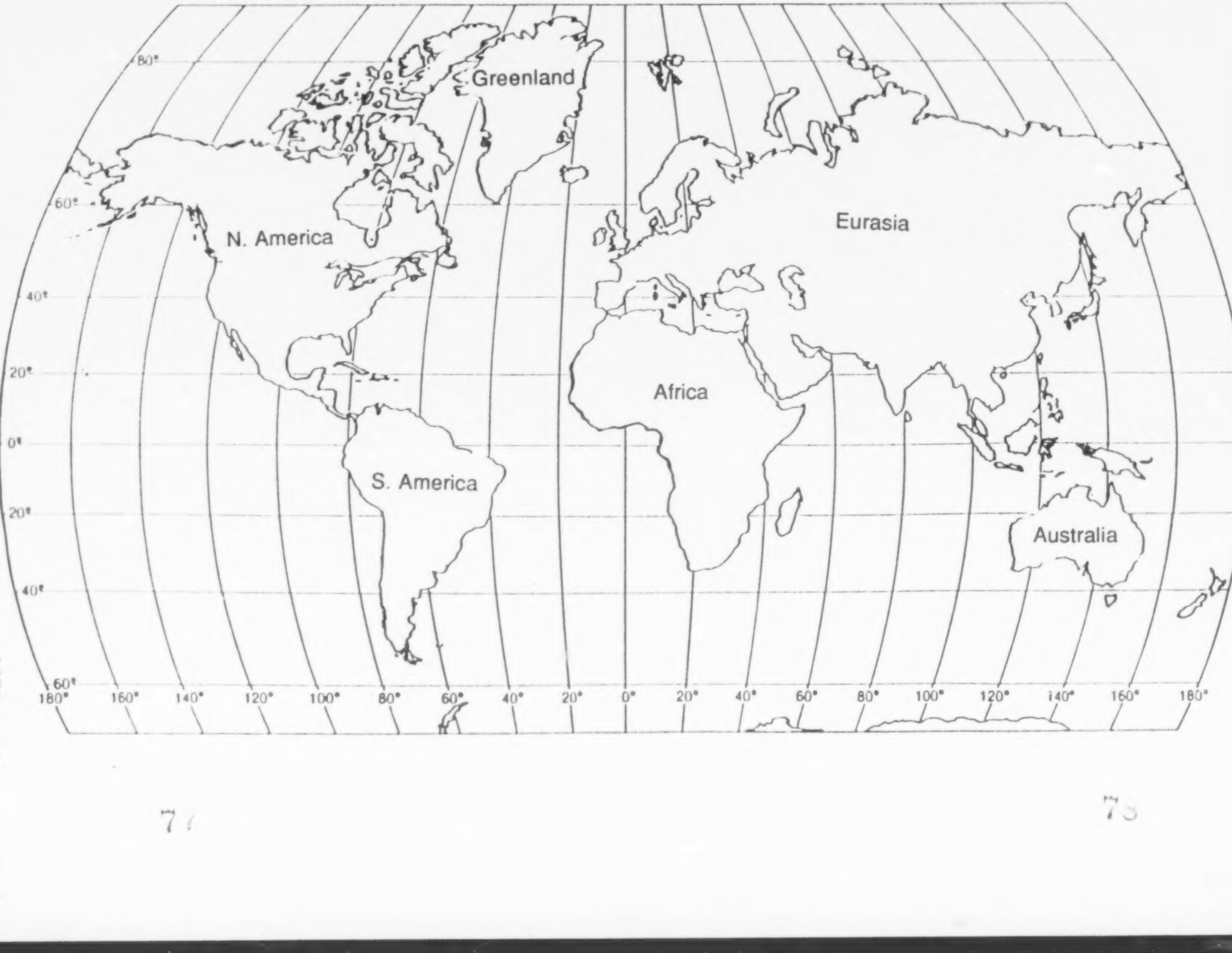
> [The technology fact sheet on GIFs gives information on how to capture NASA photos of other planets. The plots of Jupiter's moon Io clearly show a volcano on the right side of the image.]

4) Volcanologists, soil scientists and geologists study various Earth processes. What other categories of scientists could be involved in studying the elements in this activity? A volcano has erupted in Alaska. As Governor of the state, you must send a team of scientists and other people (engineers, etc.,) to study the volcano and its effects on the area. List the kinds of people you would send; give reasons for your selection. Some of the reasons should relate to their training and expertise.

5) Sulfur dioxide is a dangerous emission from volcanoes. Examine the health risk from this aerosol to a human population. Other aerosols are also emitted during volcanic eruptions. What are these and how do they influence:

   a) the health of a human population?
   b) the health of the natural environment?
   c) acid precipitation and its consequences?
   d) global climate?

6) Examine landscape paintings of famous 19th century artists such as Bierstadt. Is there any evidence of the Krakatoa eruption in any of these paintings? How is this visible? Is there any evidence in other paintings or non-scientific literature from this time that corroborate the effects of the eruption.


Greenland
N. America
Eurasia
Africa
S. America
Australia
80°
60°
40°
20°
0°
20°
40°
60°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°
60°
80°
100°
120°
140°
160°
180°

Data sheet to record the reactions of different substances - rocks, metals, water and soil - to Sulfuric Acid (H_2SO_4).

SUBSTANCE	DESCRIBE REACTION	SUBSTANCE	pH	
			BEFORE	AFTER
ROCKS: 1.		WATER SAMPLE: STREAM		
2.		RIVER		
3.		POND		
OTHER(S)		LAKE		
METALS: 1.		SOIL SAMPLE: WOODLAND		
2.		FIELD		
3.		WETLAND		
OTHER(S)		OTHER(S)		

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Teacher Background Information:

Hocking, C., Barber, J., and Coonrod, J. 1990. *Acid Rain —Teacher's Guide.* Lawrence Hall of Science, University of California, Berkeley, CA. 94720. A great source of activities on acid rain and a possible starting point for a unit on this problem, particularly human influenced acid precipitation.

Kerr, R. A. 1992. "Pinatubo Fails to Deepen the Ozone Hole." *Science.* 258 : October 16, 395, and 1989. "Volcanoes Can Muddle the Greenhouse." *Science.* 245 : 127 - 128. Two excellent accounts of the influence of volcanoes on climatic conditions.

Tilling, R. I. 1986. *Volcanoes.* U. S. Department of the Interior/Geological Survey, Federal Center, Box 25425, Denver, CO 80225. A booklet describing different types of volcanoes and various important volcanic eruptions. A great guide for the novice volcanist.

References:

Bradley, R. S. 1988. "The Explosive Volcanic Eruption Signal In the Northern Hemisphere Continental Temperature Records." *Climate Change.* 12 : 221 - 243.

Decker, R. and Decker, B. 1989. *Volcanoes.* New York: W. H. Freeman and Company.

Hoblitt, R. P. 1986. *Observations of the Eruptions of July 22 and August 7, 1980, at Mount St. Helens, Washington.* U. S. Geological Survey Professional Paper 135. U. S. Government Printing Office Washington D. C. 20402.

Mass, C. F., and Portman, D. A. 1989. "Major Volcanic Eruptions and Climate: Critical Evaluation." *Journal of Climate.* 2 : 566 - 592.

Nash, J. M. 1991. "What Makes them Blow." *Time.* June 24 42 - 44.

National Oceanic and Atmospheric Administration. 1991. Satellite images of aerosol cloud thrown into the stratosphere by the eruption of Mount Pinatubo.

Oliver, R. C. 1976. "On the Response of Hemispheric Mean Temperature to Stratospheric Dust: An Empirical Approach." *Journal of Applied Meteorology.* 15 (9) : 933 - 950. (Graph available on p. 934.)

Sear, C. B., Kelly, P. M. and Jones, P. D. 1987. "Global surface-temperature responses to major volcanic eruptions." *Nature.* 330 : 365 - 366.

Self, S., and Rampino, M. R. 1988. "The Relationship Between Volcanic Eruptions and Climate Change: Still a Conundrum?" *EOS.* 69 (6) : 74 - 86.

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II

GREENHOUSE EFFECT

IUCC
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The role of greenhouse gases

▲ **Almost all minor constituents of the atmosphere absorb some infra-red radiation — but some absorb more than others.** Drawing a clear line between "greenhouse gases" (GHGs) and "non-GHGs" is therefore not easy. But which are the gases that really matter?

▲ **All GHG concentrations are determined by a balance between "sources" and "sinks".** There are two ways mankind can increase atmospheric concentrations of GHGs: by increasing the strength of GHG sources (processes that produce GHGs) and by decreasing the strength of GHG sinks (processes that remove GHGs). Man-made sources are generally the easiest to quantify, but both sources and sinks are important.

▲ **The main greenhouse gas for the present climate is water vapour.** In the lower atmosphere, however, water vapour levels are determined by the natural balance between evaporation and rainfall. They are therefore not directly affected by human activity (although they are affected indirectly through an important feedback mechanism — see fact sheet 16).

▲ **Some GHGs are increasing as a direct result of man-made emissions.** The most important of these are carbon dioxide (CO_2), methane, and chlorofluorocarbons (CFCs). The main source of "new" CO_2 is fossil fuel emissions (figure A). Deforestation may also be significant, but it is more difficult to quantify. Once in the atmosphere, CO_2 is chemically stable and lasts for many decades.

▲ **Carbon dioxide is removed from the atmosphere by a complex network of natural sinks.** Most estimates suggest that about one-third of the CO_2 being released at present is absorbed by the oceans. Another important and related sink is photosynthesis by vegetation on land and by plankton in the sea. Most of the CO_2 absorbed by photosynthesis, however, is released again when plants and plankton decay or are eaten by animals. Only a small fraction is removed permanently.

▲ **Now that atmospheric CO_2 has risen well above its natural level, many aspects of this complex carbon cycle are changing.** The cycle may also be affected by the destruction of forests and by feedbacks between global warming and chemical and biological processes in the oceans.

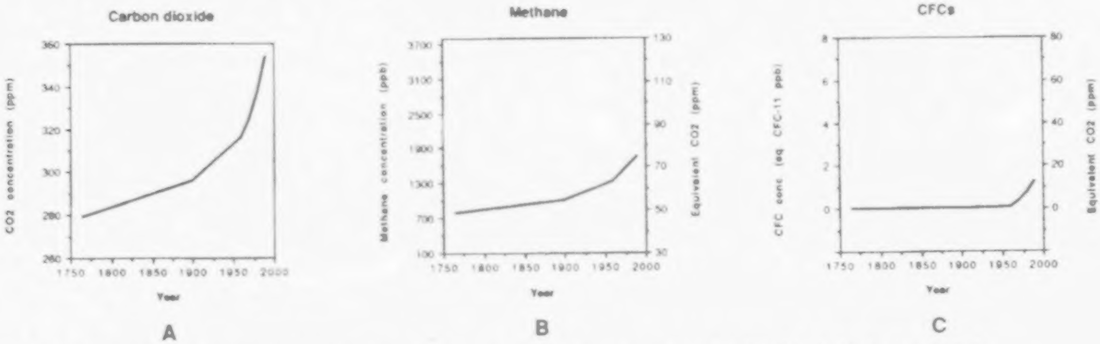
▲ **Human activity affects methane levels in several ways** (figure B). Converting land to agriculture, particularly rice paddies, releases methane. So do deforestation, coal mining, and the extraction and use of natural gas. Arctic regions may also act as a source if development (or even global warming itself) causes the release of methane frozen into tundra. Because natural sources of methane are not completely understood, methane's role in climate change is still very uncertain. Unlike CO_2, methane is destroyed by reactions with other chemicals in the atmosphere and soil, giving it a life-time of about 10 years. Human activity may also be interfering with these "sink" reactions. The increase in methane seems to have slowed recently, although scientists do not yet know why.

▲ **CFCs 11, 12, and 13 are more straightforward.** There are no natural sources, so all CFCs in the atmosphere are there because of emissions from aerosol propellants, refrigerants, foam production, and solvents. As well as attacking the ozone layer, CFCs are very powerful greenhouse gases and their levels are rising rapidly (figure C). Although concentrations should level off as the Montreal Protocol on Substances which Deplete the Ozone Layer is implemented (fact sheet 224), CFCs have long life-times, and their effects will be felt for many decades to come. By destroying ozone (itself a greenhouse gas) in the stratosphere, CFCs also affect the climate indirectly in ways that are still not fully understood.

▲ **Important GHGs, including low-altitude ozone and nitrous oxide, are increasing as an *indirect* consequence of human activity.** Ozone levels are falling only in the stratosphere (the famous "ozone hole"), where ozone is needed to protect us from ultra-violet radiation. Meanwhile, they are *rising* in the lower atmosphere. The gases responsible for creating low-level ozone are carbon monoxide, the oxides of nitrogen (all found in car exhaust fumes), methane, and other hydrocarbons. Nitrous oxide is also increasing, but for reasons that are still not well understood.

▲ **Other GHGs include HCFCs, other hydrocarbons, and halons.** Emissions of these gases have been less significant to date but might become more important as industrial processes change. This is especially true of HCFCs, levels of which are expected to increase rapidly as they replace CFCs as a result of the Montreal Protocol.

▲ **Molecule for molecule, some GHGs are much stronger than others.** As an example, figures B and C show, on their right-hand scales, concentrations of methane and CFCs in terms of "CO_2-equivalent". This is the additional concentration of CO_2 that would have approximately the same effect on the radiative properties of the atmosphere — and thus the same direct effect on climate — as the concentrations shown of those GHGs. Note that the CO_2-equivalent scales are equal. Carbon dioxide increases have dominated the enhanced greenhouse effect so far, but together the other gases now contribute to over 40% of it.



A - Concentration of carbon dioxide since 1750. Almost all of the upward trend can be directly attributed to human activity.

B - Concentration of methane and effect of methane on radiative forcing in terms of CO_2 equivalent since 1750.

C - Concentration of CFCs, in terms of CFC11-equivalent and in terms of CO_2-equivalent .

Source: Houghton et al. "Climate Change, the IPCC Scientific Assessment", Cambridge, 1990.

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Is the Earth warming up yet ?

▲ **All major climate models agree that the clearest symptom of climate change would be a global warming.** The way the atmosphere absorbs and emits radiant energy has already changed significantly because of greenhouse gas (GHG) emissions over the past 150 years. Models suggest this should have substantial climatic consequences, the clearest of which would be a sustained rise in the Earth's average near-surface temperatures.

▲ **Models still differ over whether we should yet be able to detect a significant temperature rise.** Slower-acting components of the climate system, such as the oceans, may delay any climate change by up to several decades. Because the length of this response time is difficult to predict, it is unclear how much of the climatic response to recent emissions should have happened already, and how much is still to come. Also, recent research suggests that man-made sulphur emissions may be cooling the atmosphere enough to compensate for a significant fraction of the GHG-induced warming (although pollution controls may soon reduce this effect). Nevertheless, detecting a significant rise in global average temperature over the past 100 years would be strong evidence that the climate is indeed changing as the models predict it should.

▲ **Global temperature records exist only for the past century or so.** The data available to researchers looking for temperature trends are land-based air temperature measurements and marine air-temperature and sea-surface temperature records. All begin around 1860. Before then, data collection was not systematic enough for a global record. Land-based records come mainly from meteorological stations. Marine records rely principally on observations made by merchant ships. In both cases, therefore, more observations have always been made in some regions, such as densely populated areas or well-travelled shipping lanes, than in others.

▲ **Data is very scarce for certain regions, particularly in the period before 1900.**[1] For example, ships avoid some regions in specific seasons; very few travel to the Southern Ocean during the winter even today. All data must therefore be analysed carefully to ensure that such patchy coverage does not introduce systematic biases. Since 1900, the change in spatial coverage does not seem to have affected land records significantly.[2] Before then, however, even careful analysis may lead to long-term averages that are either too warm or too cold by up to 0.1°C.[1]

▲ **Records may be affected by changes in the way observations are made.** Observation methods, such as the time of day that air temperatures are taken, affect what is recorded. If methods were applied consistently throughout an observation period, this would not matter. One meteorological station might record temperatures 0.5°C lower than another in a neighbouring country but, provided it did so consistently, both stations would record the same trend. The problem is that the methods themselves change, and the proportion of observations taken using one method in place of another also changes.

The effect of some outmoded methods, such as the pre-1940s use of uninsulated canvas buckets to gather sea-surface temperature data, can be compensated for, but only approximately.[1] Alternatively, data sources known to be heavily "contaminated" can be avoided. For example, climate researchers use only night-time marine air temperatures, as day-time records are too erratic.

▲ **Changes in the local environment may also introduce erroneous trends.** For example, cities have a significant warming effect on their local environment. Since many meteorological stations are located in or near large cities, these "urban heat islands" might introduce a spurious trend into temperature records.[3] This is the most serious possible source of systematic error to have been identified in land-based data. Considerable effort has gone into quantifying and correcting for this effect by comparing data from rural and urban stations. Generally, the remaining uncorrected effect from urban heat islands is now believed to be less than 0.1°C, and in some parts of the world it may be more than fully compensated for by other changes in measurement methods.[4] Nevertheless, this remains an important source of uncertainty.

▲ **The warming trend observed over the past century is too large to be easily dismissed as a consequence of measurement errors.** Some errors might exaggerate the apparent warming, while others might cause it to be underestimated. Their net effect is thought to be substantially less than the 0.3-0.6°C warming observed since 1860. Figures (**a**) and (**b**) show combined land and sea temperature trends since 1860 for the northern and southern hemispheres respectively. Both trends are very uneven. In the northern hemisphere, a substantial warming occurred between 1910 and 1940. Thereafter, temperatures fell by about 0.2°C to the mid-1970s, and then increased sharply again. The trend in the southern hemisphere shows a clearer warming trend beginning around the turn of the century, but it is still very uneven.

▲ **The size of the observed warming is compatible with what climate models suggest should have resulted from past GHG emissions.** It is also small enough to have been caused instead by natural variability (although it is also plausible that natural variability has temporarily masked some of the warming caused by GHG emissions). Other explanations, such as a link with the solar sunspot cycle, remain tentative suggestions. Among the various possible explanations of the observed trend in recent global temperatures, the GHG hypothesis has the strength that it is both compatible with the available evidence and is supported by a plausible physical mechanism. Nevertheless, according to the 1990 IPCC report, "the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more"

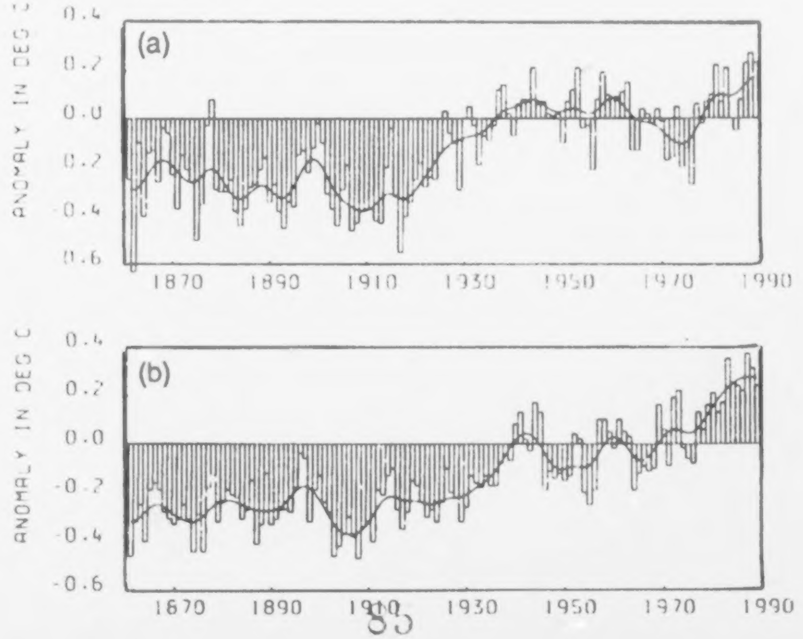
Notes:

[1] C. K. Folland et al., in "Climate Change: The IPCC Scientific Assessment", J. T. Houghton et al., eds., Cambridge, 1990

[2] P. D. Jones et al., "J. Clim. Appl. Met.", 25, 1987, pp. 161-179 and 1213-1230.

[3] R. C. Balling & S. B. Idso, "J. Geophys. Res", 94D3, 1989, pp. 3359-3363.

[4] P.D. Jones et al., "Nature", 75, No. 6289, September 1990, pp. 169-720.



Combined land air and sea surface temperatures, 1861-1989, relative to the average 1951-1980. Land air temperatures from P.D. Jones and sea surface temperatures from the UK Meteorological Office and Farmer et al. (1989).

*(**a**) Northern Hemisphere.*

*(**b**) Southern Hemisphere.*

Source: IPCC

Overview of Global Environmental Change: The Science and Social Science Issues

PAPER

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ABSTRACT

Among the many problems that the environment now faces, global warming due to our relentless burning of fossil fuels and the resultant greenhouse effect must rank at the top. The basic cause is, of course, humanity's need for energy, and currently about 80 percent of the energy we generate comes from fossil fuels (coal, petroleum, and natural gas). While a general warming trend may not be too serious by itself, it will be the accompanying shifts of rainfall and snowfall patterns, the gradual rise of sea level, the forced migration of ecological systems such as forests, and so forth, that will challenge the resourcefulness and resiliency of future generations. If we could predict exactly how these climate changes will evolve, we could be better prepared. The system that determines our climate is very complex, however, and our climate models cannot simulate it adequately, especially on a regional scale. There will be many readjustments required of mankind, and a basic imperative must be the slowing of the explosion of the population of the human race.

INTRODUCTION TO THE GREENHOUSE EFFECT

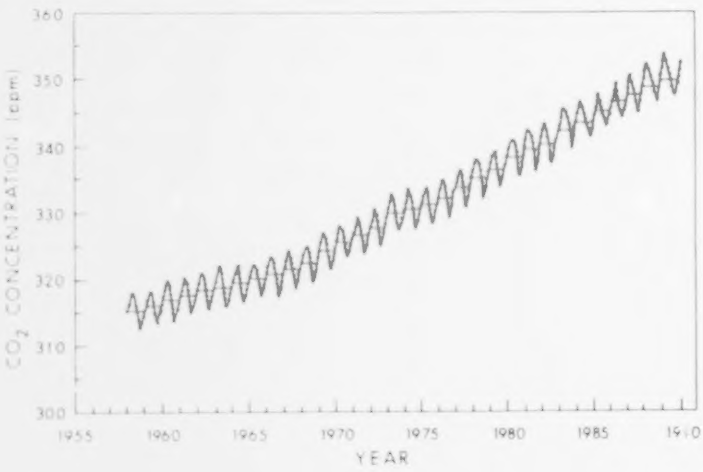
My particular interest for the past decade or more has been in the question of whether or not mankind is affecting the climate of the earth. We are changing the climate because we are changing the composition of the atmosphere, and this is in turn because we are putting enormous amounts of carbon dioxide into the atmosphere every year by burning fossil fuels. The amount is now up to nearly 6 billion tons of carbon in the form of carbon dioxide every year. The rate at which we burn fossil fuels has been steadily increasing since 1951, when the United Nations started to obtain good data on what the world was doing with its fossil fuels. From 1951 to 1973 the carbon dioxide increase had been approximately 4 percent per year, which is exponential growth with a doubling time of only fifteen years. In 1973 the OPEC oil embargo and a worldwide recession slowed the increase of fossil fuel use to approximately 2 percent per year, but that rate still has a doubling time of about thirty-five years.

We continue to increase the rate of use of fossil fuels, and in the developing world, it is going up by nearly 5 percent per year. However, in the industrialized world it is generally leveling off, even in the United States. (The exception in the United States is the increasing use of automobiles and the consequent continued increase in consumption of gasoline.) Some countries, notably Sweden and Germany, are actually decreasing their use of fossil fuels. With this being the case it is not surprising that carbon dioxide concentration is increasing in the atmosphere, a fact that we can see from the record at the Mauna Loa Observatory (Figure 1), the Point Barrow record, the American Samoa record and the South Pole station record. They all show the steady increase in concentration of carbon dioxide and of some other gases like methane and the chlorofluorocarbons.

The reason for concern is that carbon dioxide is one of the greenhouse gases. The greenhouse theory is an old theory. Jean-Baptiste Joseph Fourier in France talked about the greenhouse theory at the turn of the nineteenth century, shortly after the French Revolution. He had an idea that the atmosphere must be like a giant greenhouse, "un effet de verre," he called it, being a Frenchman, and since then various people have made calculations about how much of a warming would take place if we increased these greenhouse gases.

The greenhouse gases warm the earth in the following manner. The sun shines down and warms the earth's surface—there is actually very little absorption of sunlight in the atmo-

FIGURE 1. Concentration of carbon dioxide in the atmosphere from 1958 to mid-1990, measured at the Mauna Loa Observatory on the Island of Hawaii. The annual changes are due to the respiration of plants in the Northern Hemisphere. This set of measurements, made by C.D. Keeling of the Scripps Institution of Oceanography, is the longest continuous record, but there are now similar records from Point Barrow, Alaska, to the South Pole. (Source: IPCC, 1990)



sphere if no clouds are in the way. Obviously, the surface does not become increasingly warmer. Energy is dissipated as the surface reradiates the heat received from the sun but in a different part of the spectrum, in the infrared part of the spectrum.

Infrared radiation is the radiation that can be felt when approaching a hot stove. In fact, a former name for it was "heat radiation," since it could be felt but not seen. This infrared radiation is absorbed by carbon dioxide, by water vapor, by methane and by many other trace gases. These gases are called "greenhouse gases" because they block some of that infrared radiation from escaping to space, thereby acting like the glass of a greenhouse. The more the greenhouse gases block the infrared radiation, the warmer they keep the surface. So if we add more of those infrared absorbing gases to the atmosphere, it increases the greenhouse effect and warms the world still more. We have, in fact, already warmed the earth. Since 1900, the global average temperature, measured both at land stations and by ships at sea, has gone up by about 0.6 degrees centigrade. (If you like Fahrenheit degrees better, just double the numbers.)

Six tenths of a degree centigrade may not sound considerable, but it actually turns out to be quite significant. In the climate record that has been reconstructed for the past many thousands of years, there does not appear to be any other time when such a rapid change occurred over a period of only 100 years. When the earth came out of the last Ice Age 18,000 years ago, there was a bigger change (several degrees in going from an Ice Age into an interglacial period, such as we are in now) but that took many thousands of years to occur. Now, in just one century, we are causing 0.6 degree centigrade warming. The decade of the 1980s has had six of the warmest years on record and 1990 set still another new high.

SOME QUESTIONS ABOUT THE THEORY

As you probably have already gathered, I am fairly convinced that the greenhouse effect is here, but some of my colleagues are reluctant to admit that it is. They have various reasons for doubting the astonishing idea that mankind is warming the earth. I think that, even though scientists are supposed to be open-minded and objective, there sometimes enters a sort of "tribal guilt" on the part of some scientists who just do not want to believe that mankind can tamper with nature to that extent. They do not use that phrase, "tampering with nature," but I think this thought may be in the back of their minds.

The much more legitimate reason for doubting that mankind is actually warming the earth is simply a product of the scientific method that encourages scientists to criticize and carefully analyze any new idea. Some scientists are just not ready to accept the idea that there is enough information about this very complicated climate system to say that the greenhouse effect is being enhanced.

As an advocate of the greenhouse warming idea, I have been collecting intriguing statements, mostly from the popular press, which express the feeling that there is something wrong with this proposition that we are warming the earth (Kellogg, 1991). Here are a few of the reasons that they propose. The headlines in the distinguished *New York Times* a couple of years ago announced that a very reputable climatologist from the National Oceanic and Atmospheric Administration (NOAA) and some of his colleagues had found that, looking at the United States climate record, there was no sign of any greenhouse warming. No doubt he knew what he was talking about, but notice that it was simply an analysis of the temperature record of the stations in the lower forty-eight states. The United States occupies quite a bit less than 5 percent of the area of the globe, so what happens in the United States is not necessarily going to apply to the rest of the world, particularly to the oceans. What has actually happened in the continental United States is that the western part of the country has warmed up and the eastern part has cooled off slightly. The net effect has been little or no change in the United States.

Some also point to evidence that the North Atlantic and North Pacific oceans are both cooling, so they conclude that global warming is not taking place. It is true that the North Atlantic, and even more so the North Pacific, have actually become colder in the past twenty years.

To see if we can explain this rather surprising behavior, let us look at a recent experiment where the carbon dioxide, or the greenhouse effect, was gradually increased in the National Center for Atmospheric Research (NCAR) climate model with a circulating ocean (Washington and Meehl, 1989). Such a model of the earth's climate system is a theoretical program that tries to take into account as many of the factors that govern our climate as human ingenuity and computer speed will allow. It is essentially a set of mathematical equations that can be solved on a large computer. In the case of the NCAR model there was both a circulating global atmosphere and a circulating ocean underneath. In years 26 to 30 of the experiment (years of model time), the following occurred in this climate model: during the wintertime there was a big increase in temperature over North

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America and over Eurasia. However, the North Atlantic cooled, and the North Pacific also cooled, but to a lesser extent; during the summer the effect was less pronounced.

These occurrences can be explained by studying what happened in the model and also what has been happening recently in the real atmosphere and ocean. The warm Gulf Stream was pushed a bit further south because prevailing winds came more from the northwest than from the west, and by the same token, the cold air flowing over the North Atlantic cooled the North Atlantic. So both the ocean and the atmosphere provide an explanation for the fact that, even though the overall radiation change was leading to a warming, the net effect in the North Atlantic was a cooling.

These are just two examples of what some scientists have been invoking to try to show that the greenhouse warming idea is wrong. These scientists have been called "the environmental naysayers," and in a recent article (Kellogg, 1991) I discuss these skeptical statements—statements that are either misleading or just plain wrong, in my opinion. Naysayers believe we should not make any policy decisions until we have done much more research. That is a typical response of politicians who do not want to do anything about climate change or acid rain or any other environmental problem.

ATMOSPHERIC CHANGES CAUSED BY MANKIND

What has been said so far is an introduction to the subject of the greenhouse effect and global warming, and some of the things that skeptics, or naysayers, are saying to discredit the notion. Let us now turn to some further facts in the matter to gain a better understanding of what changes mankind is causing on Planet Earth.

I have mentioned that the concentration of carbon dioxide in the atmosphere is increasing. According to the famous Mauna Loa Observatory record on the island of Hawaii, the level of carbon dioxide in the atmosphere has been steadily climbing since recordings at that site began in 1958 (Figure 1). It has increased by nearly 30 percent since the start of the Industrial Revolution and the beginning of extensive burning of fossil fuels. It is currently rising by about 0.5 percent per year.

The concentration of methane, another infrared absorbing gas, is rising at about 1 percent per year. This increase does not come from fossil fuel burning, but is due to agriculture and other kinds of human activities like pipeline leaks and landfills.

The chlorofluorocarbons (CFCs), which are most notable because of their effect on the ozone layer, are increasing 3 or 4 percent per year, in spite of the fact that the United States and most of the industrialized countries have banned chlorofluorocarbons in spray cans. They are still being used in refrigerators and air conditioners, however, and less developed countries, including China and India, are still using chlorofluorocarbons in spray cans. The CFCs are extremely effective greenhouse gases. Table 1 summarizes the main facts about the greenhouse gases that have been mentioned and some other trace gases that also contribute to the anthropogenic global warming. Much more information about these gases and their sources and sinks can be found in the report of the International Panel on Climate Change (IPCC, 1990).

TABLE 1. The greenhouse gases

	Relative Contribution to Anthropogenic Greenhouse Effect Now (%)	Approximate Lifetime in Atmosphere (yrs)	Annual Rate of Increase (%)
Carbon Dioxide CO_2	60	50–200	0.5
Methane CH_4	15	10	0.9
Chlorofluorocarbons CFCs	12	60–100	4
Nitrous Oxide N_2O	5	150	0.3
Tropospheric Ozone O_3	8	weeks	0.5–2.0

IS PAST GLOBAL WARMING SIGNIFICANT?

The greenhouse theory has already been explained, and it predicts that an increase in the greenhouse gas concentration should cause global warming. Indeed it has, but there is some question about how significant the 0.6 degree centigrade rise in temperature really is. Could it be due to just chance, to some combination of random temperature fluctuations?

If you use a statistical signal-to-noise argument, the "signal" that we have seen is the 0.6 degrees centigrade; the "noise" is a measure of the random fluctuations, and it is 0.2 degrees centigrade. Therefore, there is what the communications people call a "signal-to-noise ratio of 3." Applying a short statistical test, we then say that the probability of that signal being real, and not just an artificial product of the noise, is more than 99 percent. In other words, there is a 99 percent probability that the signal is real and not just a product of the noise.

Dr. James Hansen, the director of the

NASA Goddard Institute for Space Studies in New York was testifying before Congress in the fall of 1988, and the Senators and Congressmen were asking him whether he believed that climate change was taking place. He is paraphrased as having said, "Yes, I think that, with about a 99 percent probability, the climate warming is occurring." He may have been drawing on a report of the World Meteorological Organization made several years earlier (WMO, 1982), where that same argument was being used. By the way, many skeptics criticized Hansen for declaring that global warming had a 99 percent probability of already having taken place (but I agree with him).

Let us hasten to add, however, that the climate change theory still has some substantial unknowns. For example, it cannot take into account changes in solar input; we know our sun is a slightly variable star. It cannot take into account changes in the ocean circulations; the more oceanographers look into this question, the more they realize that the ocean has recently had some relatively big changes in its circulation, all of which can affect the year-to-year temperature of the globe (this will be discussed in greater detail below). Furthermore, scientists are not satisfied that they are taking cloudiness into account properly in theoretical climate models. So it really should not surprise us that such a complicated system does not follow a simple, smooth increase due to the greenhouse effect. The point is that there are surely many other happenings that we cannot take fully into account.

To pursue that matter a bit further, we can be quite sure that there will be surprises in store for the world. There are dramatic and sudden changes in the past climate record that can be only partially explained, and those explanations almost invariably involve the oceans and their circulations. I have already mentioned the curious fact that, while most of the world has been warming, in the past two decades or more the surface waters of the North Atlantic and the North Pacific have been getting cooler as a result of circulation changes.

Oceanographers have been fascinated by a conjecture concerning the exchanges of surface water with the cold deep water. Henry Stommel many years ago described a three-dimensional ocean circulation pattern that has since been termed "the conveyor belt," since it accounts for the centuries-long transport of water horizontally between the oceans and vertically between the surface and the depths. Concentrating on just one part of the global oceanic conveyor belt, a major downwelling or sinking of surface water is thought to occur in winter north of Iceland in the Greenland Sea. This downwelling takes place as relatively saline Gulf Stream surface water is cooled and becomes more dense than the underlying water, and the result is convective overturning. Actually, this is not a conjecture any more since the tritium and other radioactive elements from the nuclear tests of the late 1950s and early 1960s have been observed to be slowly working their way southward in the depths of the North Atlantic, following more or less the path outlined by Stommel (Baes et al., 1985).

The aspect of this exchange that is most pertinent to the question of the greenhouse warming is that it is presumably this downwelling of surface water that transports some carbon dioxide-rich water downward, which allows the ocean to take up more of the added carbon dioxide from the atmosphere. (For the past three decades or more a little less than half of the annual addition of fossil fuel-produced carbon dioxide has been removed from the atmosphere by the oceans.) After all, the deep ocean, which stores at least sixty times more carbon dioxide than the atmosphere, must be the ultimate sink for the carbon dioxide produced by mankind.

Returning to the question of surprises, it has been suggested by several oceanographers that warming of the Arctic Ocean could result in more low-salinity water flowing northward into the Greenland Sea, and this stream of less dense water would inhibit the more saline Gulf Stream water from flowing southward into the Greenland Sea. The result, if this did happen, would be something like the following: The region where the downwelling has taken place in the past would be covered by less dense surface water. Therefore, the ocean would be stably stratified and there would be less overturning and downwelling in winter. This would cause a slowing of the conveyor belt circulation, and slower removal of the added industrial carbon dioxide from the atmosphere. This is known as a "positive feedback" since the greenhouse warming would result in more carbon dioxide remaining in the atmosphere, and hence, an even stronger greenhouse effect.

Again, this is not just conjecture about the future. Observations of the composition of bottom water in the Greenland Sea strongly suggest that the formation of new Greenland Sea deep water has slowed appreciably in the past decade (Schlosser et al., 1991). The above could provide at least part of the explanation for this remarkable but little noticed change in the ocean. It might also partly explain why there has been a more rapid increase in the atmospheric concentration of carbon dioxide in the past several years, jumping from a long-term rate of increase of about 0.3 percent per year to about 0.5 percent per year (Keeling, private communication).

THOUGHTS ABOUT THE FUTURE

If I were to make a guess about the future, I would say that by the middle of the next century we may have a doubling of the greenhouse gas concentration over its level in the mid-nineteenth century. As a result, the global warming models project a two to five degree centigrade global average temperature rise and two or three times more than that in the Arctic. These projections are shown in the far right of Figure 2. The shaded area indicates what I think will be the change in the temperature. The high scenario depends on whether we continue to burn fossil fuel at an increase of 2 percent per year, and the low scenario assumes that the world takes effective actions to limit it. These numbers are close to those adopted recently by the Intergovernmental Panel on Climate Change (IPCC, 1990).

This is not just a problem in geophysics. It is also a problem in economics and political science (Kellogg and Schware, 1982). It is indeed difficult to forecast what mankind will decide to do, and those actions will depend on the development of new technologies, such as more efficient use of energy, adoption of new nuclear generators, and a slowing of the present growth of the world population.

What does a global warming mean in human terms? It means many different things, of course. Consider Figure 3, where the shaded area on the map shows where the average temperature is between 2 degrees centigrade and 18 degrees centigrade, with an average of about 10 degrees centigrade. Geographers and anthropologists call this area "the comfort zone." When I first heard that expression I found it amusing, because people who live in the comfort zone often choose to vacation in the tropics if they can afford it. The comfort zone is where most of the wealthy and industrialized countries are located, and in between the two shaded areas is the great area of the tropics where most of the poor countries exist and where there are problems with tropical diseases and famine. Presumably this comfort zone would migrate poleward as the world warms.

However, even more important than temperature changes will be moisture changes. Rainfall has been changing in the past couple of decades at the same time the temperature has been changing, which is not surprising. If we look at the subtropics in the Northern Hemisphere (between 5 and 35 degrees north latitude), the annual rainfall has been decreasing since about 1955, but in the more northern part of the Northern Hemisphere (35 to 70 degrees north), it has been increasing. Thus, while the higher latitudes have become wetter, the equatorial zone has become drier.

FIGURE 2. Past and future globally averaged temperature and estimated polar regions temperature. The dashed line indicates the temperature record that might have taken place if there had not been any greenhouse warming. The vertical bars indicate the range between a "high" and a "low" scenario of fossil fuel use. This temperature scenario assumes that doubling of the greenhouse gases will occur about 2050 A.D. for the dotted "estimated temperature" curve, but it could be later or earlier depending largely on the rate of fossil fuel use.

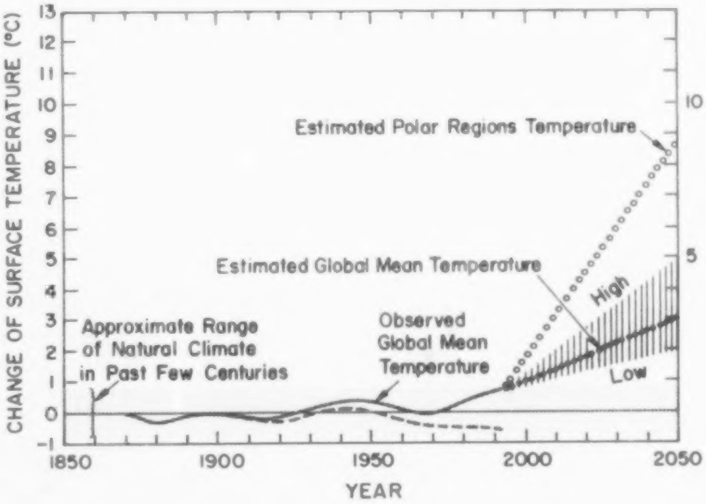
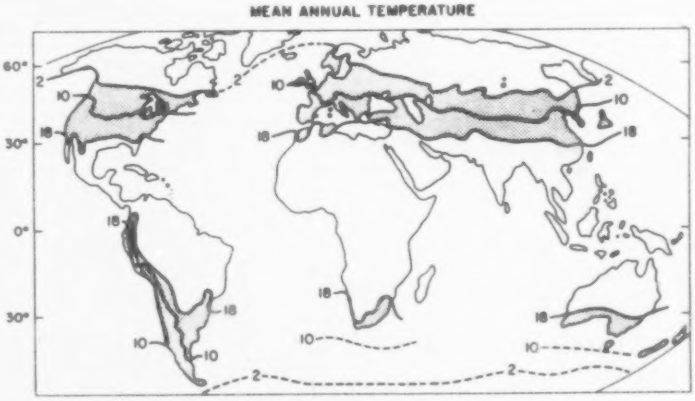


FIGURE 3. The so-called "comfort zones" (shaded areas), where the mean annual temperature lies between 2°C and 18°C. This is where the maximum demand for space heating occurs. It is also the part of the world where most of the industrialized nations lie. (Source: McKay and Allsopp, 1980).



Our model experiments show that central North America may expect a drying out in the summer, and the same may be true in central Eurasia (Figure 4). A midwest farmer does not need to be convinced of that idea; he knows that a warm summer is likely to be a dry summer.

The same thing may not necessarily be true in the winter. Our climate models show that, if anything, the winters in most of North America will be wetter. That is reassuring, because it suggests that the farmers in the midwest can switch from corn, which takes a lot of water in the summer, to winter wheat, for example. That is one of the ways these farmers may be able to adapt to the climate change.

It is interesting to note that the subtropics may become wetter according to the models, but in the past several decades, as I mentioned, the subtropics in the Northern Hemisphere have actually been getting drier. Does this suggest, perhaps, that the tropical drying trend is going to stop and rainfall will go back up again? It is too soon to make any prediction, but we can hope that this will happen for the sake of those in famine-prone North Africa and northeast Brazil.

We are now in a period when climate models are far from representing the real climate system, although they are the best tools available for forecasting the future. The important point to keep in mind is that we have to take the model forecasts with caution. Also, while they are fairly capable of depicting the global scale, they are not at all reliable in showing regional climate changes.

FIGURE 4. Example of a scenario of possible soil moisture changes on a warmer Earth. It is based on paleoclimate reconstructions of the Altithermal Period (4,500 to 8,000 years ago), comparisons of recent warm and cold years in the Northern Hemisphere, and several climate model experiments. Where there is agreement between two or more of these approaches on the direction of the change, the area of agreement is indicated with a label surrounded by a dashed line. (Source: Kellogg and Schware, 1982)

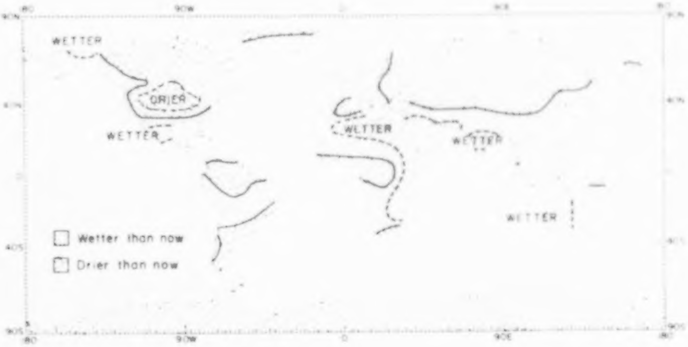
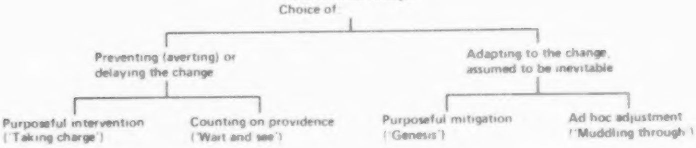


FIGURE 5. A decision tree showing the range of choices that could in principle be made in order to cope with climate change. The actions on the left would presumably have to be taken on a worldwide basis to be effective (see text), but those on the right can be taken at any level of society.


Perception of future environmental change—Choice of:
Preventing (averting) or delaying the change
Adapting to the change, assumed to be inevitable
Purposeful intervention ('Taking charge')
Counting on providence ('Wait and see')
Purposeful mitigation ('Genesis')
Ad hoc adjustment ('Muddling through')

POSSIBLE ACTIONS TO TAKE

Let us now turn to the question of what to do about the situation. There are several courses of action, as shown in Figure 5, that can be taken. Assuming that there is going to be a serious global warming, the world could take action and prevent the environmental change. To do this we would have to cut out or at least greatly reduce fossil fuel burning. Obviously, we are not going to eliminate fossil fuel burning right away. The industrialized world could not possibly do that, although several countries are now urging the rest of the world to agree to at least limiting the use of fossil fuels. That would presumably require some governmental action. Germany, Sweden, France, Italy, Holland, and even England and Japan are urging that we cut back on the use of fossil fuels by being more efficient. They have good reason to think that being more efficient would actually be economically sensible. Being more efficient would not be a hardship in the long run, they argue. For example, if the United States imposed a dollar a gallon tax on U.S. gasoline sales, some people would say that was a hardship. But it might cut back enough on driving so that we would not have to import oil from the Middle East, which would be to our advantage. That is the kind of tradeoff that is involved when one begins to think about the longer term future.

While a "muddling through" is probably the most likely course (as shown at the right of Figure 5), a better course is to accept the notion that climate change is more or less inevitable and then to prepare for it. My colleague Stephen Schneider called it the "Genesis Strategy," based on the story of Joseph in Egypt (Schneider, 1976). You will remember that the Old Testament credits Joseph with making the first accurate climate forecast, and he persuaded the Pharaoh to store the wheat of Egypt during the plentiful years so that they had some during the following seven years of famine. The Genesis Strategy makes good sense for a number of reasons.

Here are some of the measures that might be taken to increase our ability to get through a climate change (Kellogg and Schware, 1982). We might protect arable soil, improve water management, and apply agro-technology, that is, develop other strains of crops and trees that will grow in the new climate. We could improve coastal land-use policies, recognizing that sea level is likely to rise. The last blue ribbon committee report considering sea level forecasted that it could rise about a third of a meter by the middle of the next century (IPCC, 1990). That is enough to cause some trouble along seacoasts everywhere.

Then, of course, to slow the climate change, energy conservation should be a number one priority since this would reduce the consumption of fossil fuels and the release of carbon dioxide. Part of any energy conservation strategy would be to develop renewable resources, these being various forms of solar energy, hydropower, geothermal, and (yes) nuclear electricity generators.

Under the Reagan administration, our federal investment in solar energy and other renewable energy resources almost came to a halt, although now there is some federal money going back into it. The argument was that if solar energy is such a good thing, then industry should sponsor the research and development involved. Actually, industry did this to some extent. For example, the efficiency of the thin photovoltaic films that convert solar energy directly to electricity has increased by about a factor of ten in the last ten years, and they have become cheaper, too. I think that in the next decade, electrical energy will be generated from the sun competitively with fossil fuels, and this will be a big step forward.

So that is where we stand, with the European countries and Japan wanting to agree to slow the use of fossil fuels, the United States, China, Russia, India, and most of the Third World countries not willing to agree. In 1992 there will be a major United Nations sponsored international meeting in Rio de Janeiro on the environment and development, and we will see then if the beginning of an international agreement or protocol can be adopted that would effectively slow the worldwide use of fossil fuels.

One cannot leave this enormously important and complex subject without emphasizing that the basic worldwide environmental problem is *too many people*. The human population of the planet is still increasing at several percent per year, with the greatest growth being in many of the poor countries of the Third World that cannot feed and clothe their people now. The pressure of human activities on the global environment cannot be relieved if the population continues to soar upward. That is surely our major challenge, now and in the years ahead.

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Balancing the Budget

Carbon Dioxide Sources and Sinks, and the Effects of Industry

Taro Takahashi, Pieter P. Tans, and Inez Fung

Many observations support the notion that greenhouse warming is already occurring.

Molecules of carbon dioxide (CO_2) and other trace gases absorb infrared radiation or heat. An atmospheric increase in these infrared-absorbing gases, which include water vapor, methane, and chlorofluorocarbon (the Freons or CFCs) would permit less heat to escape from Earth's surface into space. The atmosphere would retain more heat, in the way a greenhouse holds heat, and this "greenhouse effect" may be accompanied by some dire consequences: Regional desertification, dramatic sea-level rise, and an increase in both the frequency and intensity of hurricanes have been predicted.

Greenhouse gases are measured regularly (from hourly to monthly, depending upon the intended purpose) all over the world, and chemical analyses of air bubbles trapped in old glacial ice provide pre-industrial concentrations. These measurements show that the atmospheric carbon dioxide concentration has increased by 25 percent since the pre-industrial period (1750 to 1800), from about 280 parts per million then to 350 parts per million by volume today. The concentration of methane has nearly doubled, from about 800 to 1,700 parts per billion since the pre-industrial time. The CFCs have gone from zero, prior to 1950, to about 600 parts per trillion today.

Many observations support the notion that greenhouse warming is already occurring. For example, global sea level has been increasing at a rate of 15 to 25 centimeters per century during the past 100 years, perhaps due to glacial melting in polar regions and thermal expansion of seawater. Global mean air temperature (computed using select sets of meteorological observations) exhibits a warming trend of about 0.7°C since 1880. Variations in the oxygen isotope ratio found in deep ice cores from Greenland and Antarctica infer a temperature record for the past 160,000 years, which includes the last major Ice Age ending about 12,000 years ago. We find that the temperature record correlates very well with carbon dioxide concentration measured in air bubbles trapped within ice crystals: higher temperatures and higher carbon dioxide concentrations are coincident. The 0.7°C warming over the past 100 years is substantial,

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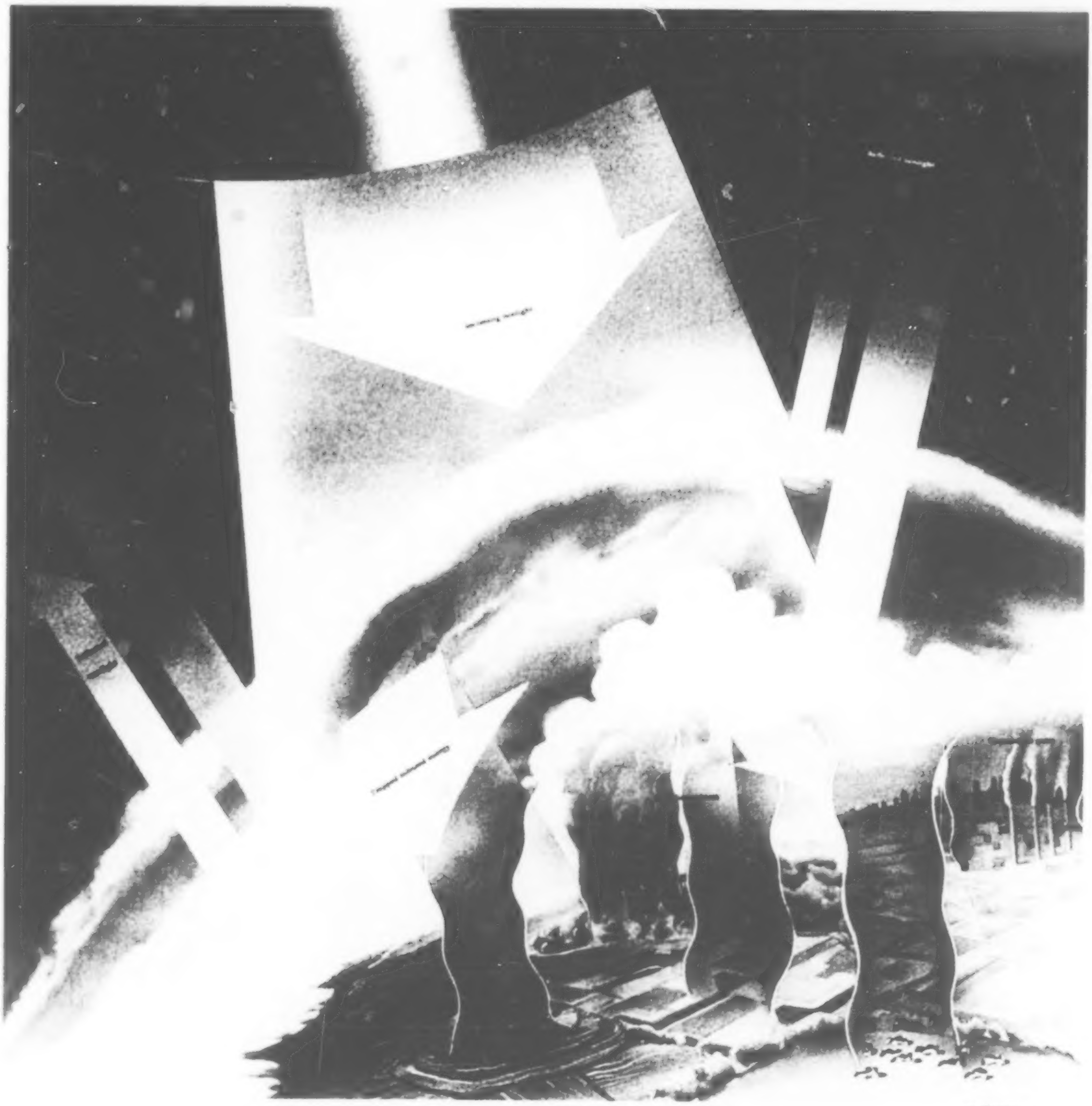


Ian Worpole

even when compared with temperature excursions Earth has experienced over geological time.

We must be careful when interpreting these observations, however. On the one hand, it is not possible to tell from the data presented in the figure on the next page whether the increase in atmospheric carbon dioxide concentration in the past 160,000 years has caused the global warming or, vice versa, the warming has induced the atmospheric carbon dioxide increase. Therefore, although highly suggestive, this graph cannot be used as proof that global warming is a result of increasing atmospheric carbon dioxide. On the other hand, the carbon dioxide increase in the past 100 years is entirely man-made, and the 0.7°C warming observed over the same period is consistent with some predic-

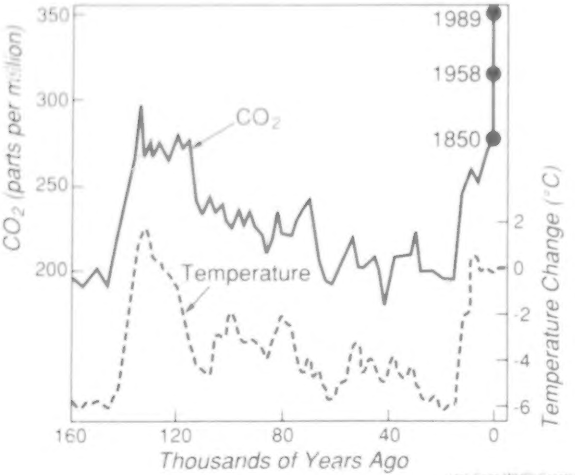
One theory holds that the carbon dioxide released into the atmosphere (as a result of human activities) is trapping the sun's heat, causing the global temperature to rise.

tions based on advanced climate model calculations that include the effects of atmospheric greenhouse gas buildup. Although this supports the theory of global warming due to greenhouse gases in the air as the result of human activity, this amount of warming or cooling has occurred numerous times in Earth's history. So, the recent warming trend may represent an event in natural variability that has nothing to do with human activities. Both believers and skeptics of human-induced global warming will have to wait until new evidence in favor of one view or the other is uncovered.

Why is Carbon Dioxide Important?

Our study concerns the fate of industrial carbon dioxide released into the atmosphere. According to global climate model computation results obtained by James Hansen and colleagues (NASA's Goddard Institute for Space Studies, in 1988), about 55 percent of predicted global warming is attributed to carbon dioxide, 20 percent to CFCs, and the remaining 25 percent to methane and nitrous oxide. In the future, CFC emissions will be reduced according to the Montreal International Protocol for CFC production, and the atmospheric concentration of CFCs could be halved in 50 to 80 years. On the other hand, carbon dioxide is produced as a final combustion product of industrial and domestic carbon-containing fuels as well as through cement manufacturing. It is also released into the atmosphere when forests are cut and burned and when organic matter decays. Because carbon-based fuels (including oil, coal, natural gases, and firewood) are so basic to human activities that range from manufacturing and transportation to heating, cooling, and cooking, its consumption is expected to increase as long as the human population continues to increase, regardless of national levels of industrialization and living standards. It is, therefore, important to understand what controls the rate of carbon dioxide accumulation in the atmosphere.

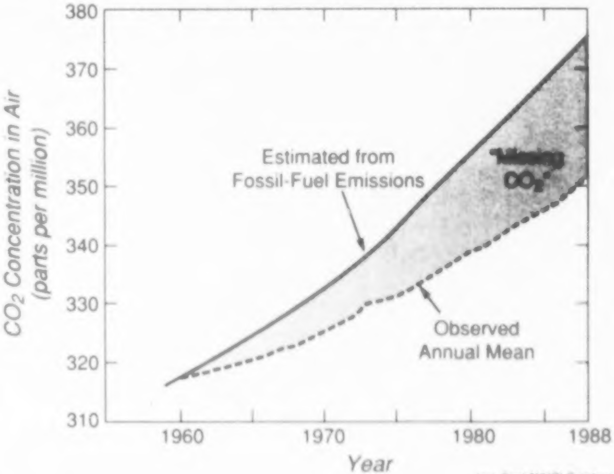
Changes in temperature and atmospheric carbon dioxide (CO_2) during the past 160,000 years are charted. The temperature record was estimated based on variations in the oxygen-18/oxygen-16 isotope ratio found in Antarctic ice-core samples. Atmospheric CO_2 concentrations were measured in air bubbles trapped in glacial ice. The results were obtained by a French and Soviet scientific team (Lorius et al, Nature*, 1990).*



Jack Cook/WHOI Graphics

The observed rate of atmospheric increase is about half of the industrial carbon dioxide emission rate. This indicates that about half of the industrial carbon dioxide released into air has been absorbed by natural reservoirs, most likely the oceans and land biosphere, which includes plants, trees, and organics in soil. In other words, carbon dioxide accumulation in the air, and hence possible carbon dioxide-induced global warming, has been somewhat alleviated by the partial disappearance of industrial carbon dioxide.

Two important questions may be asked. The first is "Where does the missing carbon dioxide go?" The answer will help us formulate strategies for alleviating or slowing the carbon dioxide accumulation rate in air. For example, if the forests are found to be a major sink (absorber) for industrial carbon dioxide, ongoing deforestation must be strongly discouraged or prevented, and tree planting should be encouraged. The second question is "What would happen to the missing carbon dioxide if the climate became warmer?" If the proportion of missing carbon dioxide decreases in response to global warming, industrial carbon dioxide would accumulate in the air at a faster rate. This is a positive-feedback condition that could lead to a faster rate of global warming, and hence to global disaster. On the other hand, if warming causes carbon reservoirs to absorb more carbon dioxide (for example, by more rapid growth of plants), then carbon dioxide-induced warming would cause a reduction in the carbon dioxide accumulation rate in the atmosphere, thus slowing down the warming trend. Eventually, this warming trend would settle down to a certain level due to this negative feedback process. Both scenarios are possible. Here we will address the first question. Although the second question is both relevant and challenging, the answer can only come in the future with diligent, long-term observations and research.



Jack Cook/WHOI Graphics

If all industrial emissions stayed in the atmosphere, we would expect the upper curve to reflect atmospheric CO_2 concentrations. The difference between this estimated amount and the mean annual atmospheric CO_2 concentration that has been measured (by C.D. Keeling of Scripps Institution of Oceanography) indicates the amount of "missing CO_2." For 1958, expected and observed values are assumed to be the same.

Early Estimates for Oceanic Uptake of Industrial Carbon Dioxide

Atmospheric carbon dioxide concentration is regulated by a dynamic balance between carbon dioxide supply and demand by carbon reservoirs. The oceans and land biosphere are two major reservoirs exchanging carbon dioxide with the atmosphere at a significant rate. Hans Oeschger, Uli Siegenthaler, and their colleagues (University of Bern, Switzerland), and Wally Broecker (Lamont-Doherty Geological Observatory of Columbia University), and Tsung-hung Peng (Oak Ridge National Laboratory), among others, formulated computer models to simulate industrial carbon dioxide uptake by an idealized atmosphere and ocean. The world ocean was represented by a two-layer box of water with a 75-meter-thick surface layer and a 4,000-meter-thick deep layer. The atmosphere was represented by a single homogeneous body that exchanged carbon dioxide across the sea surface.

According to the models, the carbon dioxide gas entered the surface layer and diffused into the deep layer. Rates of carbon dioxide movements were estimated using the measured distribution of natural radioactive carbon-14 in the air and oceans. Since carbon-14 atoms are in the form of carbon dioxide molecules, their distribution should closely approximate the uptake and spreading of industrial carbon dioxide in the oceans. As observed in ice cores, the pre-industrial carbon dioxide concentration in the atmosphere was steady at about 280 parts per million, so the researchers considered that carbon dioxide sources and sinks were balanced then. In addition, they assumed that atmospheric carbon dioxide was in equilibrium with the surface-water layer in 1850. To this initial condition, industrial carbon dioxide was added to the atmospheric box at rates closely approximating actual industrial records. Because the annual effect of industrial carbon dioxide was small, it was treated in the model as a perturbation, and the biological effect on the carbon cycle in the oceans was assumed to be unchanged.

North Pole air contains, on average, about 3 parts per million more carbon dioxide than South Pole air.

Their results show that 30 to 35 percent of industrial carbon dioxide should be taken up by oceans, 15 to 20 percent should be taken up by the land biosphere, and the remaining 50 percent should remain in the atmosphere. Hence the oceans are the most important sink for industrial carbon dioxide. More recent studies by Jorge Sarmiento (Princeton University) and his associates at the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration (NOAA) employ an advanced three-dimensional ocean circulation model instead of the highly idealized one-dimensional ocean models used for the earlier studies. However, they assumed that the surface layers of pre-industrial oceans were initially in equilibrium with atmospheric carbon dioxide everywhere in the world, and treated the industrial effect as a perturbation. As we will show, this assumption is inconsistent with observations. Their estimates of carbon dioxide uptake are similar to those of the earlier studies based upon idealized oceans.

A New Approach

Our basic premise is that carbon dioxide concentration in a given atmospheric position is governed by the transport of carbon dioxide in the air by wind and other air motions as well as by the geographic and temporal patterns of carbon dioxide sinks and sources. The carbon dioxide distribution in air has been measured at many locations on Earth, and the location and intensity of industrial sources have been estimated from energy consumption statistics. The oceanic carbon dioxide sinks and sources over the Northern Hemisphere and equatorial oceans have been measured aboard research vessels and commercial ships. However, the distribution and intensity of carbon dioxide sinks and sources over the land biosphere are poorly known, as are those over the Southern Hemisphere oceans, especially during the winter period. We have therefore used the following three sets of known information, in conjunction with the advanced three-dimensional model for global atmospheric circulation, and obtained estimates for the two unknowns: the carbon dioxide sink/source intensities for the land biosphere and the Southern Hemisphere oceans.

North-South Difference in Atmospheric Carbon Dioxide. Accurate monitoring of atmospheric carbon dioxide concentration was started by C.D. Keeling and his associates (Scripps Institution of Oceanography) during the International Geophysical Year in 1957. Their observational data show that during the last decade carbon dioxide concentration has been increasing at a mean rate of about 1.4 parts per million per year. This corresponds to an atmospheric carbon dioxide increase of about 3.0 billion tons as carbon per year during the past several years. Furthermore, based upon measurements obtained between 1981 and 1987 at

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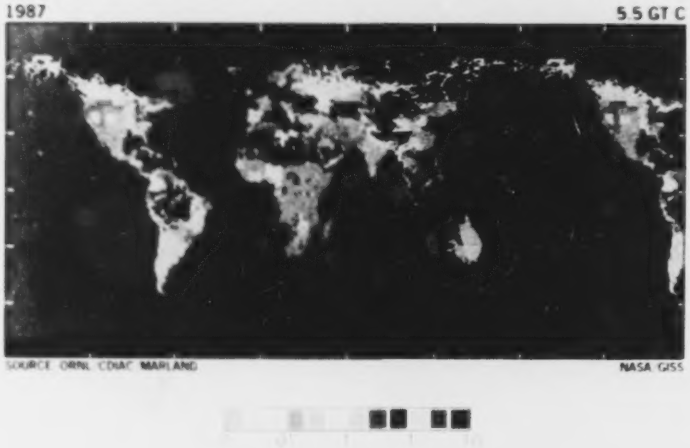
some 20 stations located all over the world, the scientists at the Climate Monitoring and Diagnostics Laboratory of NOAA in Boulder, Colorado, demonstrated that annual mean carbon dioxide concentrations in northern air are greater than that of southern air. North Pole air contains, on average, about 3 parts per million more carbon dioxide than South Pole air. This information is very important to our study, since the north-south gradient of the atmospheric carbon dioxide concentration is affected by the distribution of carbon dioxide sinks and sources as well as by the rate of large-scale atmospheric mixing between the Northern and Southern hemispheres.

Industrial Sources of Carbon Dioxide. The industrial carbon dioxide emission rate has been estimated, based on United Nations and other governmental records for fossil-fuels and cement production. However, the global carbon dioxide emission rate cannot be estimated as precisely as desired. For example, coal is a major fossil fuel, produced and consumed in Eastern European countries and the Peoples Republic of China.

CO_2 RELEASE FROM FOSSIL FUEL COMBUSTION



SOURCE ORNL CDIAC MARLAND

kilograms per centimeter squared, per meter

As the colors indicate, industrial CO_2 sources are unevenly distributed throughout the world. The US is responsible for the highest level of CO_2 emissions (22 percent) followed by the former USSR region (18 percent), the Peoples Republic of China (10 percent), Japan (5 percent), Germany (4.5 percent), India (3 percent), and the UK (2.6 percent). The remaining 34.9 percent is distributed throughout other regions. (Courtesy of G. Marland, Oak Ridge National Laboratory.)

Together these countries are responsible for more than 30 percent of the world's industrial carbon dioxide emissions, while the US emits 22 percent. However, since their carbon contents or BTU (British thermal units) are poorly known, carbon dioxide emissions cannot be reliably computed based on the production tonnage of coal.

Gregg Marland (Oak Ridge National Laboratories) places the uncertainty of global carbon dioxide emissions (such as the ones shown on page 21) to about 13 percent. Based on the information provided by Marland, we estimate that the mean annual industrial carbon dioxide emission rate from 1981 to 1987 was 5.3 billion tons (as carbon) per year. The geographical distribution data for the industrial sources have been compiled by Marland, and his data are used in the three-dimensional GISS/NOAA general circulation model of the atmosphere above. About

96 percent of the annual emissions are from northern sources.

Oceanic Carbon Dioxide Sinks and Sources. The net carbon dioxide flux across the sea surface may be characterized by the chemical driving force and the gas-transfer rate coefficient. The former is the difference between the partial pressure of carbon dioxide in surface ocean water and that in the overlying air. This tells, like relative humidity, whether water is undersaturated or supersaturated with atmospheric carbon dioxide. The transfer rate is a difficult quantity to measure at sea, and hence is estimated via special laboratory or field experiments. Multiplying these two quantities yields the net carbon dioxide flux across the sea surface.

[illegible]

Carbon dioxide partial pressure measurements conducted by scientists at Lamont-Doherty Geological Observatory and NOAA's Pacific Marine Environmental Laboratories in Seattle, Washington, are summarized in the graph opposite.The upper panel represents the 1972 to 1989 mean distribution during the four-month period of January through April, and the lower panel represents that for July through October. Generally, warm equatorial waters, especially those in the Pacific equatorial zone, are a strong source of carbon dioxide to the atmosphere, whereas colder waters in higher latitudes are carbon dioxide sinks. The Pacific equatorial waters are the most important oceanic carbon dioxide source, and are sustained by upwelling of carbon dioxide-rich subsurface waters. Although the seasonal variability of the source intensity is relatively minor (about 25 percent) during the normal, non-El Niño years, this source is eliminated by the blanketing effect of warm, low-carbon dioxide surface water, which spreads eastward from the western Pacific during an El Niño event (see The Interplay of El Niño and La Niña, *Oceanus*, Summer 1989). Such an event is known to occur once every five to seven years.

The map also reveals that a subarctic area in the western North Pacific Ocean is a strong carbon dioxide source during the northern winter, when the water is coldest, but becomes a strong carbon dioxide sink during summer when the water is warmest. Similar seasonal changes have been observed in the Weddell Sea, near Antarctica. During winter, the surface water is chilled and becomes more dense than the underlying deep waters, thus setting off deep convective circulation. This causes nutrient-rich deep waters rich in carbon dioxide (see figure 1 on page 24, *Oceanus*, Summer 1989) to rise to the surface. Accordingly, carbon dioxide trapped in deep water is released to the atmosphere during this deep convection period in winter. In spring and summer, more sunlight becomes available, stimulating rapid phytoplankton growth in surface ocean waters. This growth utilizes carbon dioxide and nutrients that were brought up to surface during the previous winter, and reduces the carbon dioxide partial pressure in the surface water to below the atmospheric level. This occurs despite substantial warming of the water, which by itself causes the carbon dioxide partial pressure in water to increase. Thus, proliferation of photosynthetic plankton in summer is mainly responsible for the ocean becoming a carbon dioxide sink in these high-latitude regions. Biological productivity in the great oceanic gyres at temperate latitudes is very low. As a result, the seasonal changes of the carbon dioxide partial pressure in those regions are driven mainly by seasonal temperature changes.

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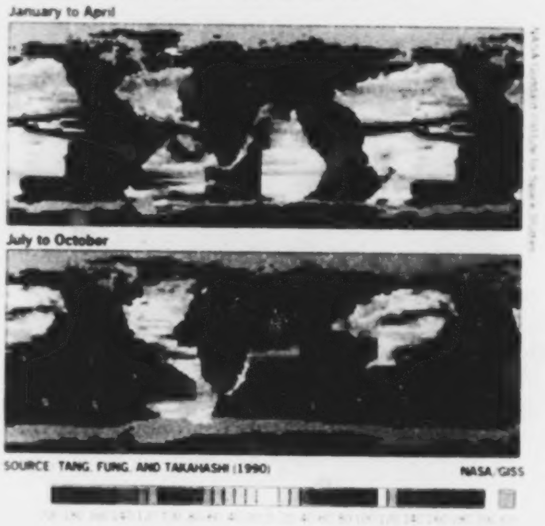
Change in CO_2 Partial Pressure



SOURCE: TANG, FUNG, AND TAKAHASHI (1990)

Using color to depict CO_2 partial pressures (expressed in microatmospheres), this map illustrates the observed differences between CO_2 concentrations in the atmosphere and the surface ocean to reveal CO_2 transfer between them. Mean values for normal, non-El Niño years from 1972 to 1989 are presented for two four-month periods, January through April and July through October. The oceanic CO_2 sink areas, where atmospheric CO_2 is taken up by seawater, are shown in blue to green, and oceanic source areas, where surface ocean water is releasing CO_2 into air, are shown in yellow to purple. White indicates areas where no net transfer occurs, and black indicates areas for which we have no measurements during these two seasonal periods.

Across the sea surface, the carbon dioxide gas-transfer coefficient is primarily determined by the degree of turbulence of air above and water below the interface. For practical reasons, it is often expressed as a function of wind speed. At wind speeds below about 3 meters per second, the sea surface is hardly stirred and looks like a mirror. Under these conditions, the carbon dioxide gas exchange rate is very low. At higher wind speeds, the gas is transferred across the sea surface at a higher rate. However, the results of field and laboratory experiments differ by as much as 100 percent. For this discussion, we will use a wind speed dependence that has been estimated on the basis of the air-sea distribution of radioactive carbon-14 produced by natural processes and nuclear-bomb tests (see figure 4 on page 28, *Oceanus*, Summer 1989). Using this relationship in concert with the mean monthly distribution of wind speed over the global oceans and the sea-air carbon dioxide partial pressure difference, the net carbon dioxide flux across the sea surface has been computed. The carbon dioxide values in areas where measurements have not been made were estimated from temperature-carbon dioxide correlations of adjacent areas. In this way, we found that the Pacific, Atlantic, and Indian oceans north of the 15°N parallel together take up about 0.6 billion tons of carbon as carbon dioxide annually, whereas the equatorial belt (15°N to 15°S) of these three oceans releases about 1.3 billion tons of carbon as carbon dioxide during a normal, non-El Niño year. Since equatorial release exceeds northern ocean uptake, balancing the global oceanic carbon dioxide budget hinges upon the sink intensity of the southern oceans.

Atmospheric General Circulation Model. An important computational model ties these observations together. Commonly called a General Circulation Model or GCM, this model mathematically describes large-scale global circulation of the atmosphere, based on a number of physics principles. It has been used to predict global climate changes as well as to study gas dispersion in the atmosphere. The GCM we used was developed by James Hansen and his associates. The earth's surface is divided into boxes, each 4° latitude by 5° longitude [in mid-latitudes, this corresponds to an area about 250 miles (east to west) by 280 miles (north to south)], and the atmospheric column above the boxes is divided into nine layers, according to pressure or height above ground level. In each box, energy from the sun is exchanged between the layers via absorption, reflection, and re-remission of light and heat by ground surfaces and clouds, via evaporation, condensation, and precipitation of water (clouds, rain, and snow), and via air motion (winds and turbulence).

Reduced atmospheric carbon dioxide in summer indicates that land-plant growth extracts a large quantity of carbon dioxide from air.

The model was fine-tuned by adjusting "eddy mixing" of air in each box, so that observed atmospheric distributions of krypton-85 and CFCs were matched. These man-made gases are ideally suited for testing and calibrating the transport of air in these atmospheric circulation models, since their sources are located in the industrial north like the industrial carbon dioxide sources. Furthermore, they are only sparingly soluble in seawater and are not taken up by land biosphere via photosynthesis. As a final test for the model, seasonal variation of atmospheric carbon dioxide concentration at various altitudes was calculated using satellite-based land photosynthesis and respiration data previously obtained by Fung and her associates in 1987, and compared with observed values over Scandinavia and Australia.The computed results are in good agreement with the observations, giving us confidence in the model.

Using the GCM described, we first determined the effect of industrial carbon dioxide sources alone. A world industrial carbon dioxide emission of 5.3 billion tons of carbon per year was added to the model with the global distribution as illustrated in the figure on page 23. When charted, it is apparent that a strong northern sink is required to reduce carbon dioxide concentrations in northern air and flatten the north-south gradient, thus making the computed and observed curves agree.

Global Carbon Dioxide Budget

The observation that atmospheric carbon dioxide concentration is reduced substantially during summer, particularly in the Northern Hemisphere, indicates that the growth of land plants extracts a large quantity of carbon dioxide from the air even though a portion of the fixed carbon may be returned to the air by plant decay. A survey of New England areas has shown that forests have been recovering from the deforestation inflicted during pioneer days. On the other hand, deforestation is currently in progress in tropical areas of Brazil and Southeast Asia where farmlands and forests are being removed and houses are being built. Because of the highly uneven and diverse distribution of land plants and soil carbon, it is not possible to extrapolate local changes to a global scale. Although satellite surveys show areal changes in land use and vegetation in many regions, they do not give changes in the mass of soil carbon and plant carbon. Accordingly, we have attempted to estimate the amount of carbon dioxide taken up by the land biosphere based on measurements made in the air and oceans.

With our method, we tried to estimate the flux of carbon dioxide uptake by the southern oceans and land biosphere using the atmospheric GCM and available observations. The following quantities are considered known, as discussed earlier:

- global industrial carbon dioxide emissions of 5.3 billion tons of carbon per year, and its distribution,
- mean annual north-south gradient in atmospheric carbon dioxide

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concentration (3 parts per million from the North Pole to the South Pole),
- net carbon dioxide sink and source fluxes over the oceanic areas north of 15°S latitude, and their distribution, and
- global forest distribution and relative intensity of photosynthesis and respiration, including that of tropical deforested areas.

Information for global forest distribution was obtained through high-resolution color scanning satellite observations by NOAA. In addition, on the basis of published information, we believe plant growth rates may be enhanced by increased carbon dioxide concentrations in air (called the "carbon dioxide fertilization effect"), up to 5 percent or an additional 3 billion tons of carbon per year, and that tropical deforestation activities annually release 1 to 2.5 billion tons of carbon (as carbon dioxide) into the air. The carbon dioxide uptake rate by the southern oceans and the terrestrial biota have been computed for a variety of realistic scenarios. In all cases, our calculation demands that the amount of carbon dioxide taken up by various reservoirs be balanced with that released from industrial and deforestation activities. Two common features emerge in many cases attempted. First, a strong carbon dioxide sink by temperate forests of 2 to 3 billion tons of carbon per year is needed to account for the observed north-south gradient of atmospheric carbon dioxide. Second, the southern oceans should take up 1 to 1.5 billion tons of carbon annually. This estimate is consistent with the limited number of carbon dioxide measurements made over the southern oceans. This means that global oceanic flux values estimated from measured and computed values combined are less than 1 billion tons of carbon, and are far smaller (one-third or less) than those for global land-biosphere uptake, which ranges between 1.6 and 2.0 billion tons. In contrast with earlier estimates, the major sink for industrial carbon dioxide released into the atmosphere appears to be not the oceans, but the northern forests! This conclusion is not significantly affected, even if much lower values for carbon dioxide gas-exchange rates across the sea surface are used.

In contrast with earlier estimates, the major sink for industrial carbon dioxide released into the atmosphere appears to be not the oceans, but the northern forests!

Qualifying Our Conclusions

Our attempt to obtain an improved carbon cycle inventory using available data for carbon dioxide in the atmosphere and oceans has lead us to conclude that the biospheric uptake of industrial carbon dioxide is significantly greater than the oceanic uptake, and that the northern forests are sequestering a considerable portion of industrial carbon dioxide. If our conclusion is correct, this would have serious implications for national and international energy policies. To alleviate accelerated carbon dioxide accumulation in the atmosphere, increased forest productivity via advanced ecosystem management should be encouraged, in combination with reduced deforestation activities.

However, we feel that our conclusion requires further scrutiny and testing with additional scientific information. Our carbon dioxide inventory computation predicts that 2 to 4 billion tons of carbon should be accumulating in the northern forest ecosystems each year. If carbon is accumulating at this rate evenly over the northern land areas, there would be an increase in carbon standing crop of 25 to 50 grams per square meter each year, or 500 to 1,000 grams of carbon per square meter

(1 to 2 pounds of carbon per square yard) for 25 years. The carbon standing crop is the total amount of all the forms of carbon present over an entire unit area of land, and includes plants, litters, and soil carbon. Since the average standing crop of land biomass is about 13 kilograms per square meter, the predicted increase corresponds to 4 to 8 percent of the standing crop. Therefore, if our estimates are correct, the northern forested areas have gained several percent of carbon standing crops as living trees, litter, and soil carbon. Is it there? Presently, too little information is available to substantiate or refute our conclusion.

To alleviate accelerated carbon dioxide accumulation in the atmosphere, increased forest productivity should be encouraged, in combination with reduced deforestation activities.

Our conclusion may be also tested using changes in the stable-carbon isotope ratio, carbon-13/carbon-12, in atmospheric carbon dioxide. Since the carbon atoms released from fossil fuels are depleted in the heavier isotope, carbon-13, by about 2 percent, compared with those in atmospheric carbon dioxide, the emission of fossil-fuel carbon would make atmospheric carbon isotopically lighter. This effect is counteracted by photosynthetic utilization of carbon dioxide by land plants, which would preferentially take up lighter carbon-12 and thus cause the remaining atmospheric carbon dioxide to become heavier. Although the carbon isotope ratio in air is thus partially controlled by these two processes, its space and time variation is also affected by the carbon dioxide exchange of both isotopes with the oceans. Therefore, observed changes in the carbon isotope ratio in atmospheric carbon dioxide are not large, but could yield information on biological carbon dioxide sinks. However, the resulting estimates are sensitive to the difference between the isotopic ratio for current photosynthetic carbon fixation and that in carbon dioxide released by the decomposition of older organic debris in the biosphere. Continued investigations of the carbon isotope ratio should yield independent information on the fate of industrial carbon dioxide in the future.

Taro Takahashi is a marine geochemist and Associate Director of the Lamont-Doherty Geological Observatory of Columbia University. Since the International Geophysical Year, 1957 to 1959, he has been engaged in a global study of carbon dioxide in the oceans. In 1958, he discovered a solitary seamount in the eastern South Atlantic Ocean and named it the Vema Seamount. He is Chairman of the Ocean Carbon Dioxide Committee, National Research Council.

Pieter P. Tans is a physicist working at the Climate Monitoring and Diagnostics Laboratory of the National Oceanic and Atmospheric Administration in Boulder, Colorado. Since his graduate-student days in the Netherlands, he has been interested in man's impact on the global climate and in greenhouse gases in the atmosphere and oceans. He has also probed the behavior of air and water as a small-sailboat racer.

Inez Fung is an atmospheric physicist at the NASA Goddard Institute for Space Studies in New York City. Her current activities in carbon-cycle modeling and climate modeling grew out of seeds planted during her undergraduate and graduate studies. In 1989 she was awarded NASA's Exceptional Scientific Achievement Medal.

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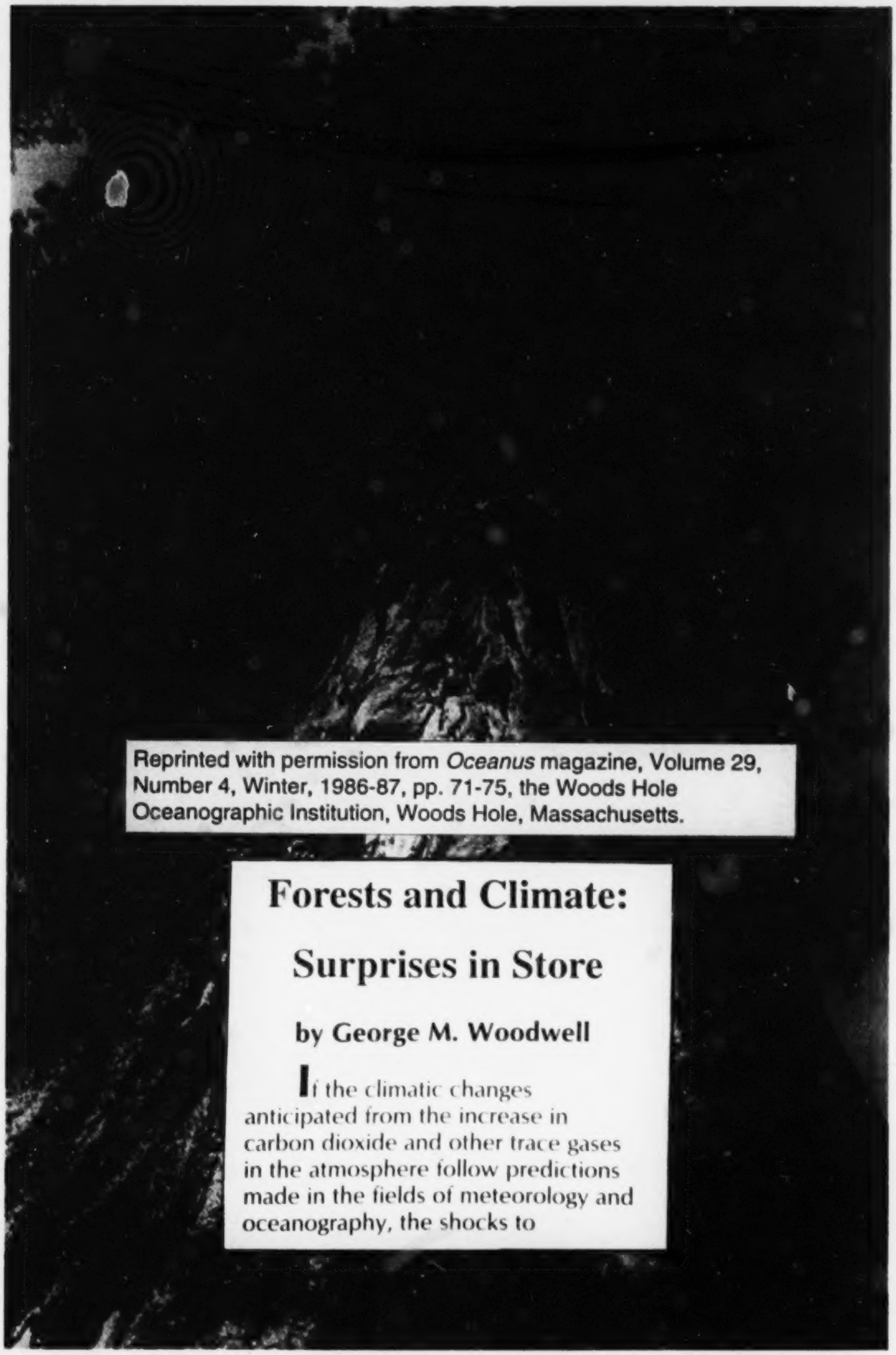

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Forests and Climate:

Surprises in Store

by George M. Woodwell

If the climatic changes anticipated from the increase in carbon dioxide and other trace gases in the atmosphere follow predictions made in the fields of meteorology and oceanography, the shocks to

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contemporary civilization will be substantial. The analyses predict the beginning of an indefinite period of global warming. The warming will be greatest near the poles; there will be little change in the tropics. The analyses have been based on physical and chemical data. However, they have included only superficial consideration of the biotic interactions that affect the atmosphere. The biotic considerations are important because they throw long-standing assumptions into question, and show that the climatic changes are likely to be more serious and threatening than commonly envisioned. Measurements in 1986 by P. D. Jones and others as reported in the British magazine *Nature* suggest that the warming trend is now under way.

The carbon dioxide content of the atmosphere has been rising throughout the last century. The amount in the atmosphere is now about 350 parts per million by volume, 25 to 30 percent above the amount present a century ago. The cause of the increase is generally accepted as the combustion of fossil fuels. However, evidence suggests that the destruction of forests over the last century and a half was the major source of carbon dioxide released into the atmosphere until the middle 1960s.

The current release of carbon into the atmosphere from the combustion of fossil fuels is about 5×10^{15} grams annually. There is further release from deforestation that is difficult to measure. Recent estimates suggest that this release is in the range of $0.5\text{–}4.7 \times 10^{15}$ grams. The total amount of carbon released annually into the atmosphere from these two sources probably lies in the range of $6\text{–}9 \times 10^{15}$ grams, (6 to 9 billion metric tons) but the actual amount is not known.

The atmospheric concentration is easily observed. It is rising at about 1.5 parts per million, equivalent to 3.0×10^{15} grams annually. The difference between the total amount emitted into the atmosphere and the amount that accumulates in the atmosphere is absorbed into the oceans or into the terrestrial biota and soils.

These views are widely accepted, at least up to the point where there is a significant additional release of carbon from the terrestrial biota into the atmosphere. But studies of deforestation show that this additional increment must be added to the release from fossil fuels to determine the total effect of human activities. Studies of oceanic uptake of carbon dioxide, however, seem to show that the amount absorbed by the oceans is limited to less than the difference between the amount accumulating in the atmosphere and the total released from fossil fuels. That is, some of the CO_2 from the burning of fossil fuels cannot be accounted for in our budgets, let alone the excess CO_2 expected because of deforestation. If this is correct, the forests are either absorbing carbon from the atmosphere, or, releasing an amount that is equal to a very small fraction of the fossil fuel release. For this reason a mechanism has been sought that would cause the biota to store an increasing amount of carbon as the atmospheric concentration increases.

The Role of the Biota

The issues become more complicated, confusing, and threatening when the potential influence of the biota is considered more carefully. The amount of carbon held in reservoirs that are directly under biotic control is large by comparison with the amount held in the atmosphere. These large, biotically-controlled reservoirs are on land, although the potential of planktonic populations in the sea for sequestering carbon cannot be overlooked.

The largest reservoirs of carbon compounds on land are in the plants and soils of forests. The total amount held in plants globally is in the range of 500 to 700×10^{15} grams, or more; the amount held in soils is uncertain, but commonly thought to be about $1{,}500 \times 10^{15}$ grams. These two reservoirs contain about 3 times the amount held in the atmosphere. A small change in the metabolic processes that affect the size of the terrestrial pools has the potential for affecting the atmospheric composition appreciably.

The importance of these biotic processes is emphasized in the sinusoidal annual oscillation conspicuous in the data from monitoring stations of the middle and high latitudes in the Northern Hemisphere (page 9). The oscillation is now widely accepted as caused by the annual cycle of metabolism of seasonal forests. Their metabolism is dominated in spring and summer by net photosynthesis that results in a net storage of carbon in plants and soils. Consequently, the concentration of CO_2 in the atmosphere is reduced. During fall and winter, on the other hand, respiration dominates and there is a net release of stored carbon into the atmosphere. Obviously, any small change in the rate of one of these processes has the potential for affecting the composition of the atmosphere significantly in a few weeks. The question is, what can be anticipated as the composition of the atmosphere changes and the global climate warms?

The Mauna Loa Record

Recently a consistent year-by-year increase in the amplitude of the oscillation observed at the Mauna Loa station in Hawaii has been measured. The increase was assumed immediately by some to be the result of a stimulation of carbon fixation by the increase in the concentration of carbon dioxide in the atmosphere. They reasoned that because carbon dioxide is required for photosynthesis, an increase in the concentration of CO_2 in the atmosphere would increase the rate of carbon fixation and the total amount of carbon removed by the biota seasonally. Such an effect would be consistent with current models based on limited absorption by the oceans.

The argument is supported by abundant experimental evidence showing that increased concentrations of carbon dioxide in air increase rates of growth of plants in agriculture. There is, however, no evidence from natural populations that the 25 to 30 percent increase in carbon dioxide in the atmosphere over the last century has increased the general growth of trees or other perennials. Even in agriculture where other factors, such as water and nutrients, can be kept available, the stimulation of growth from a 25 to 30 percent increase in carbon dioxide is small, and probably not more than a few percent under the best circumstances.

But quite apart from the naiveté inherent in accepting a feebly supported assumption, the amplitude of the oscillation is obviously the sum of photosynthesis and respiration over some segment of the hemisphere. Is it possible that respiration also might be stimulated in some way, generally or seasonally? What are the factors that affect the ratio of gross photosynthesis to total respiration in terrestrial ecosystems?

Terrestrial Metabolism

It is, of course, difficult to measure the metabolism of terrestrial ecosystems as units and even more difficult to experiment with the factors that may control their metabolism. Measurements have been made, however, under limited sets of circumstances. It is also possible to infer from more narrowly focused physiological experiments how forests might be expected to behave as physical conditions change.

In any review of the list of factors that affect photosynthesis and respiration, and might be important in shifting the ratio of these processes, the availability of energy, water, mineral nutrient elements, and changes in temperature all have large effects. The availability of water and nutrients, for example, commonly affects production in agriculture. The concentration of carbon dioxide appears in this list, but far down, and its effect is small by comparison with effects expected from other factors.

Temperature, on the other hand, may have profound effects on rates of respiration, but very little direct effect on rates of photosynthesis. A 10-degree Celsius increase in temperature close to the normal temperature for a species commonly induces a change in the rate of respiration of 1.5 times to more than 4 times the previous rate. Similar relationships exist for organic soils in the Arctic and probably for terrestrial ecosystems in general, but because of limited evidence, the question is far from resolved, despite its potential importance in determining climate.

The data available from studies of ecosystems are limited because research on ecosystems as units has been limited. In one program that did take place, a series of efforts was made at Brookhaven National Laboratory in the 1960s to examine the metabolism of forests. Various techniques were used, including an array of specially-designed chambers. The underlying principle was to measure continuously the amount of carbon dioxide absorbed or emitted over time as an index of metabolism, net photosynthesis in green tissues during daylight, and respiration. In one study, nocturnal temperature increases resulted in the accumulation of carbon dioxide within a forest over a period of several hours. The rate of increase in the concentration of carbon dioxide was assumed to be correlated with its rate of emission and with the rate of respiration of the ecosystem. Data were taken for more than 40 such inversions over the course of one year. Correlations with temperature were observable with different curves defined for winter and summer.

The change in the rate of respiration for a 10-degree Celsius change in temperature is referred to by physiologists as a Q10. A Q10 of 2 means that a 10 degree Celsius increase in temperature produces a doubling of the rate of respiration. In the data from the forest of central Long Island, the Q10s for the separate curves defining respiration for winter and summer were similar, 1.3 to 1.5, although the rates at the same temperature differed appreciably between winter and summer. A Q10 calculated between winter and summer was much higher, about 3.5.

The experience is much too limited to be used widely in calculations such as these. It is being supplemented now by studies of the metabolism of arctic tundra, but there are few data that define forest respiration rates as a function of environmental factors. The most reasonable assumption at the moment seems to be that the Q10 for forest respiration is of the order of 1.3 to more than 3.0. That means that an increase in temperature of 1 degree Celsius can be expected to increase the rate of forest respiration as a whole by between 3 and 25 percent. A warming in the middle to high latitudes is expected over the next one to three decades of several degrees Celsius. The warming could easily double the rates of respiration in the current biota, including soils. Is there a parallel effect on photosynthesis that can be expected to compensate for such a stimulation of respiration in forests?

Climatic Change and Forests

Ecologists have little difficulty in proving the migration of forests as climates have changed in the past. The forests of New England have all developed on land churned by glacial activity within the last 15,000 years and there is evidence that the adjustments of natural communities are still under way. Treelines migrate, species migrate, and soils are built and destroyed as physical and chemical circumstances change. But, the response times for forests are commonly measured in decades to centuries, not years to decades.

Sudden changes in climate, or in other conditions, bring the devastation of forests that we are seeing now in Europe and in eastern North America in response to the combination of factors embraced by "acid rain." Forests can be destroyed rapidly; they are replaced, but slowly over a century or more. Similarly, as climates change, forests will migrate in time, but the potential exists for the destructive effects to outstrip the rate of repair.

The effect of such changes on forests is clear. When respiration outstrips photosynthesis, plants and other organisms cease growth and ultimately die. In the longer term they are replaced by other species adapted to the new conditions, but in the short term of decades, the effect is

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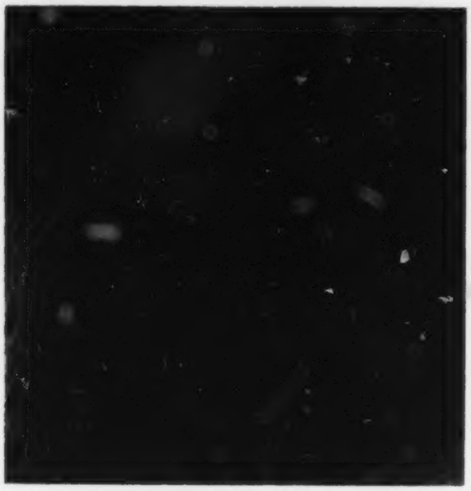

Deforestation in the state of Rondonia, in the southwest Amazon basin, as photographed by Landsat in August 1978. The image covers a ground area 185 kilometers on a side, and shows roads cut into the forest. The government later gave away 100-hectare tracts to individuals who cleared the land.

widespread mortality of trees without replacement. This mortality results in the decay of some fraction of the large pools of carbon held in forests of these latitudes with the subsequent release of the carbon as carbon dioxide. The amount of carbon available for such release is large, certainly in the range of hundreds of billions of tons (10^{15} grams). This carbon is released in addition to the carbon released through combustion of fossil fuels and deforestation.

The most reasonable prognostications are that there will be substantial changes in climate in the forested zones over the next years to decades, and that these changes will be but the forerunner of more changes. Under those circumstances the stabilization of climate required for the re-establishment of forests in zones in which forests have been lost will be long in coming and the impoverishment will be widespread and persistent.

An Example

The problem can best be understood by considering the transition from the deciduous (leaf-bearing) forests of temperate eastern North America to the coniferous (cone-bearing evergreen) forests of more northern and mountainous regions. As the climate warms, the evergreen forests of the north move further northward. At the Southern boundary of the region, at the transition to deciduous forest, there is widespread mortality of coniferous trees and other species associated with them. In the course of a decade, the mortality may spread many miles northward. The deciduous forest does not migrate rapidly, but slowly. The effect is widespread mortality of trees and other species near their limits of distribution: a wave of biotic impoverishment as profound as any change imposed by the glaciation.

The effect is not limited to forests, of course. It will reach to all vegetations, especially those of the middle to higher latitudes where the climatic changes are greatest. But the most important change may be in the carbon cycle itself, for the destruction of forests and soils in this way will almost certainly result in a substantial further release of carbon from biotic pools into the atmosphere. The amount of the release is difficult to estimate, but it has the potential of releasing hundreds of billions of tons of carbon over years to decades, depending on the speed of the warming. Such releases are significant in the global balance and will accelerate the warming. It is difficult to envision any set of parallel changes in the biota that would reduce this positive feedback system over the period of years to decades before the most vulnerable pools of carbon are exhausted.

How Can We Manage Such Problems?

The transitions discussed are thought by some to be under way at the moment, although the evidence is not yet conclusive in the eyes of all. The potential effects, however, of initiating an indefinite period of rapid global climatic change are profound. They include the possibility of a significant positive feedback through biotic effects, which include the destruction of forests over large areas in the middle to higher latitudes, and the beginning of a continuing disruption of agriculture as climates change around the world. The sudden destruction of forests by air pollution, now being experienced in northern and central Europe and in the eastern mountains of North America, is but a sample of the destruction that appears to be in store as the climatic changes anticipated become reality over the next years.

The issue is unquestionably one of the most urgent topics for the agenda of the councils of nations. It strikes at the core of the question of the continued habitability of the Earth at the very moment that the human population is passing 5 billion on its unplanned and uncontrolled upward path. It has a potential for disruption of the human enterprise over a few decades that rivals the chaos of war. The issue will force itself onto the agendas of governments. The question is, when will it be addressed, and how effectively. For the moment, the issue seems to be in the hands of a small group of scientists who struggle with very modest budgets, probably no more than $30 million annually worldwide, to test whether present forecasts are indeed as threatening as they appear to be. All the answers available at present appear to confirm their apprehensions.

Several steps are appropriate now. First, there is a clear need for additional detail on the carbon cycle. The terrestrial component is large and, at the moment, neglected. Research to define places and rates of deforestation and the response of terrestrial ecosystems to climatic change is appropriate now. It is not under way. While there

Clearing in the Brazilian Amazon Basin. Very little of the lumber is salvaged. The trees are cut, allowed to dry, and then burned. The cleared land often supports crops for two to three years before being abandoned to become unproductive cattle pasture.

is now an excellent monitoring system available for recording the changes in atmospheric carbon dioxide, there is no systematic program to monitor the effects of the great forested zones of the Earth on the atmosphere. Such a program would be cheap and extremely valuable. None is even proposed at the moment. The transfer of atmospheric carbon into the oceans, discussed in the articles beginning on page 9, also warrants more intensified study.

But the greatest challenge at the moment is to introduce the issue of climate change into the councils of governments—because solutions will require unified action. That action will involve unified policies in the use of fossil fuels and other sources of energy, and global policies in the management of forests, especially the world's remaining tropical forests. Time is short. Action should be taken before climate change causes widespread social disruptions, not after.

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Reprinted with permission from *Greenhouses—Are They Always Buildings?* pp. 7-9, 1992, Zaner-Bloser, Inc., Columbus, Ohio.

LESSON 1

Is Earth Like a Greenhouse?

Earth is surrounded by a blanket of air that acts a lot like the glass in a greenhouse. Just like greenhouse glass, the blanket of air surrounding Earth allows more of the Sun's heat to come in than it allows to get out. Scientists call the warming of the air around Earth the *greenhouse effect.*

Some rays from the Sun never reach Earth. They bounce back into space off the clouds. A few rays reach Earth and bounce back off sand, ice, or snow. About half of all rays are absorbed by things on the ground, such as fields, pavement, houses, and lakes.

Have you ever walked barefoot on a black road on a very hot day? Dark places like roads and plowed fields get very hot in the Sun. Like warmed flowerpots in a greenhouse, the warmed places of Earth give off heat. Some of this heat passes into space, but most of it is trapped by the air around Earth. This has raised the temperature of Earth about 60 degrees Fahrenheit (35 degrees Celsius) higher than it would be otherwise. Natural forces have created a temperature balance, and living things have adjusted to it.

7

LESSON 1

Purposes

- To recall what is known about greenhouses
- To order and classify information about the greenhouse effect
- To identify main ideas about how the earth's atmosphere produces the greenhouse effect
- To identify relationships between solutions to global warming and their results
- To elaborate and summarize possible solutions to global warming
- To engage in metacognitive thinking

students to recall what they know about the warming process in a greenhouse.

the question posed at the top of page 7 and ask students to predict how Earth might be compared to a greenhouse.

student ideas on the chalkboard.

(Text Pages 7, 8, and 9)

the students to read the text, or read it with them.

the students in interpreting the accompanying diagrams and in comparing the information in the text about the warming process of Earth with their predicted ideas listed on the chalkboard.

Optional

Science Connection
Making a Greenhouse

soil and small plants.

each student to bring in a rinsed two-liter clear plastic soda bottle.

all the way around the bottle just above the plastic base. This makes a base for the greenhouse.

students to put soil and small plants in their bases, water the soil modestly, and replace the plastic tops. Secure the sides so that air does not pass through.

students to predict how long their plants will live without further watering.

how their greenhouse is like a model of Earth with its own atmosphere.

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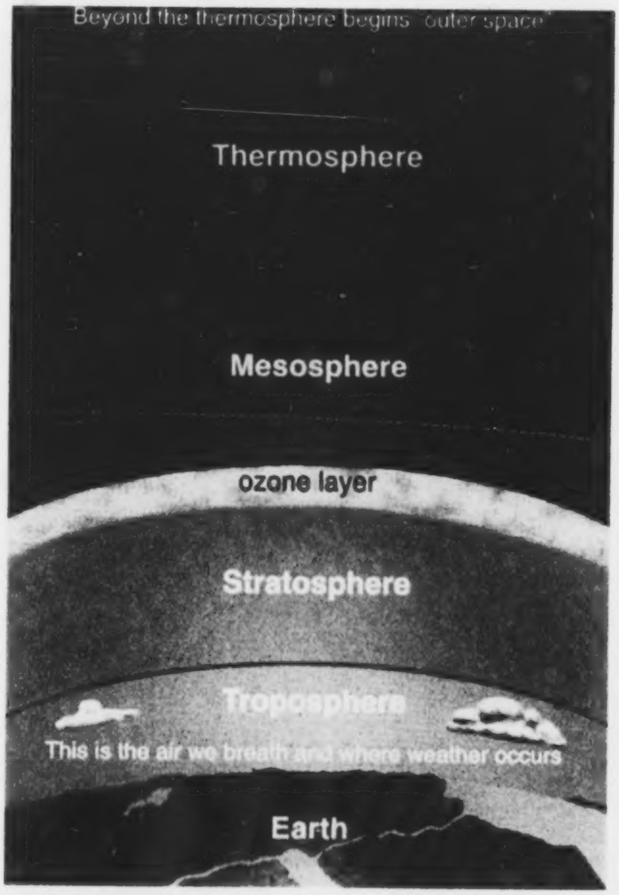
LESSON 1

The blanket of air surrounding Earth is called the atmosphere. The atmosphere is made of gases, water vapor, dust, and dirt. The atmosphere stretches hundreds of miles out from Earth's surface. The diagram on this page shows four major layers of the atmosphere. Because the air can be compressed by the pull of gravity, the atmosphere is much more dense or "thick" in its lower layers than it is far above the ground.

Two gases make up almost all of the lower atmosphere where we live. Those gases are nitrogen and oxygen. The atmosphere is also made up of very small amounts of other gases called trace gases. Some of these trace gases trap heat and keep it from going back into space. These gases are called greenhouse gases. Some greenhouse gases are made by people.


Beyond the thermosphere begins "outer space"
Thermosphere
Mesosphere
ozone layer
Stratosphere
Troposphere
This is the air we breath and where weather occurs
Earth

Newsworthy Notes

The Sun's Spectrum

Not all rays from the Sun are the same. The Sun produces energy by means of nuclear reactions. This energy travels to Earth in waves of various lengths. The distance from the top of one wave to the top of the next is called the wavelength, and this distance can be measured.

Light waves have different characteristics depending upon their wavelength. Light waves with shorter wavelengths have higher energies. Gamma rays and X rays have such high energies that they can pass through people's bodies unchanged. Gamma rays and X rays can also be deadly to living things.

Ultraviolet rays are longer in wavelength than gamma and X rays. In addition to burning the skin and causing melanoma (a type of skin cancer), ultraviolet rays from the Sun have high enough energy that they can kill small organisms.

The light we see has longer wavelengths than ultraviolet rays. Although visible light appears white, it is actually made up of many different colors.

Infrared radiation has a longer wavelength than that of visible light. We cannot see infrared radiation, but we can feel it as heat. Some snakes have special sensory organs which allow them to sense infrared radiation or heat. Microwaves have a longer wavelength than infrared. We use microwaves for radar, medicine, communications, and to heat food.

Radio waves have the longest wavelength. We change the height (amplitude) and wavelengths of radio waves to transmit radio through space.

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The natural balance of gases in the atmosphere is just right for people, animals, and plants. Think about it. Animals and people breathe oxygen to live. If there were too little oxygen on Earth, what do you think could happen?

What if there were too much of the greenhouse gases trapping heat on Earth? Do you think Earth could get too hot? Some scientists are afraid that Earth is getting warmer and may one day be too hot.

Optional

Science Connection

Which Absorbs More Heat?

[illegible] students why they think icy and snow-covered areas reflect light, while oceans and fields absorb it. Guide the discussion to include color as a factor.

[illegible] with white and black tempera paint or construction paper placed close to an incandescent light or in direct sunlight. Monitor the temperatures using thermometers or touch.

[illegible] students in observing how different Earth materials heat up differently due to color. Have pupils touch the pavement, parking lot, grass areas, rocks, and buildings to feel the difference.

Social Studies Connections

Career Opportunities

[illegible] about jobs relevant to this unit such as gardener, florist, scientist, farmer, and climatologist.

[illegible] students to role-play various jobs, and ask classmates to guess what job is being portrayed.

Trip to a Greenhouse

[illegible] a greenhouse at a local nursery, farm, or garden center.

[illegible] the guide to focus student attention on working in a greenhouse as well as on plants that grow in a greenhouse. (If a field trip is impossible, invite a florist, gardener, or farmer to visit the class as a guest speaker.)

[illegible] up with thank-you notes written and illustrated by the students.

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Session 2: Modeling the Greenhouse Effect

Overview

In this session, the students perform an experiment to learn about the greenhouse effect. By constructing a physical model of the atmosphere using familiar materials, the students discover that air trapped in a container will heat up more than air in an open container, when both are exposed to the same amount of energy from a light bulb. In a comparable (but different) way, the carbon dioxide in the atmosphere acts as a "heat trap" for energy from the Sun.

The objectives of this session are to: (1) provide basic information about the Earth's atmosphere and how scientists use models to study it; (2) provide students with an opportunity to build and test a physical model analogous to the atmospheric greenhouse effect; (3) introduce the concepts of energy transfer and thermal equilibrium; and (4) give students practice in setting up controlled experiments, accurately recording data, graphing, and interpreting the results.

Reprinted with permission from "Global Warming and the Greenhouse Effect," Great Explorations in Math and Science (GEMS) series, pp. 21-32. This activity is the second session of an eight-session unit. The unit includes other hands-on experiments and a "world conference on global warming." The GEMS series features more than 35 teacher's guides for a wide age range. These guides are available from GEMS, Lawrence Hall of Science, University of California, Berkeley, CA 94720. GEMS materials are copyright by the Regents of the University of California.

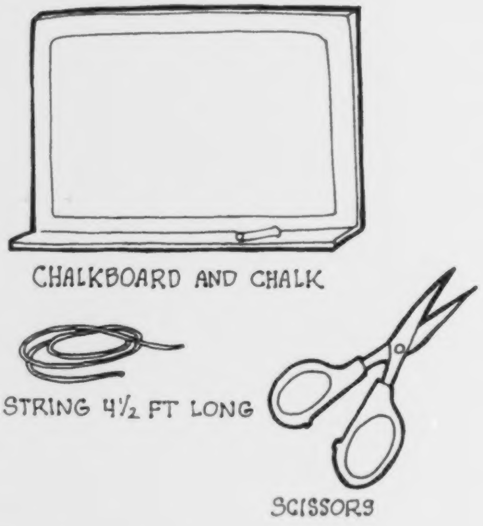
What You Need

For the class:

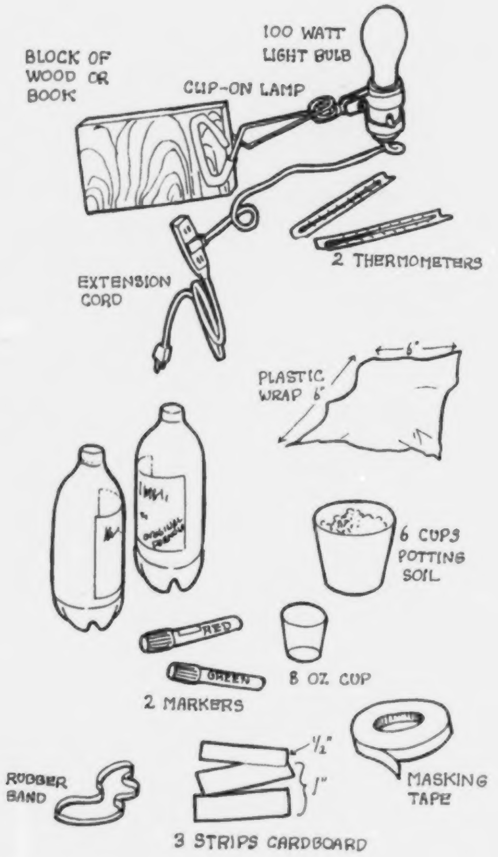
- ☐ 1 piece of string, 4½ feet long
- ☐ white chalk and chalkboard, or marking pen and butcher paper
- ☐ 1 scissors

For each group of 4 students:

- ☐ 2 two-liter clear plastic soda bottles
- ☐ 2 thermometers
- ☐ 3 strips of thin cardboard, ½" × 1"
- ☐ 6 cups of potting soil
- ☐ 2 marker pens (one red, one green)
- ☐ 1 roll masking tape
- ☐ 1 piece plastic wrap, approximately 6" x 6"
- ☐ 1 rubber band
- ☐ 1 100 watt light bulb
- ☐ 1 clip-on lamp
- ☐ 1 extension cord (if needed to connect lamp to power outlet)
- ☐ 1 large book or piece of wood for securing the lamp
- ☐ 1 plastic 8-oz. cup
- ☐ 2 graphing data sheets, entitled "The Greenhouse Effect" (master included, page 32).

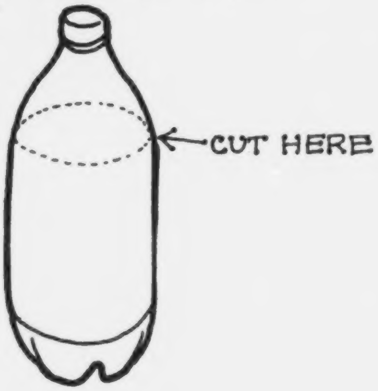


FOR THE CLASS


BLOCK OF WOOD OR BOOK
100 WATT LIGHT BULB
CLIP-ON LAMP
2 THERMOMETERS
EXTENSION CORD
PLASTIC WRAP 6"
6"
6 CUPS POTTING SOIL
RED
GREEN
2 MARKERS
8 OZ. CUP
½"
1"
RUBBER BAND
MASKING TAPE
3 STRIPS CARDBOARD

FOR EACH GROUP OF 4 STUDENTS

If you have extra time to devote to this session, allow your students to prepare the experimental equipment themselves. Alternatively, you may want some student volunteers to help you set up the equipment before class.



Getting Ready

Before the Day of the Activity

1. Collect 2-liter plastic soda bottles (two for each team of four students.) Cut them off at the point where they begin to narrow at the neck.

2. Tagboard or a manila folder can be used to make a strip of thin cardboard, ½" wide by 1" long, to be used as a spacer, to locate the two bottles exactly ½" inch from the light bulb. Cut two squares of cardboard to cover the bulbs of the thermometers so they are shaded from the direct rays of the light bulb.

On the Day of the Activity

1. Tie the chalk onto one end of the string. Standing next to the board, place your foot on the free end of the string and practice drawing an arc with a 4-foot radius. (as shown on page 25)

2. Make copies of the graphing data sheet, "The Greenhouse Effect" (one copy for every two students, master on page 32).

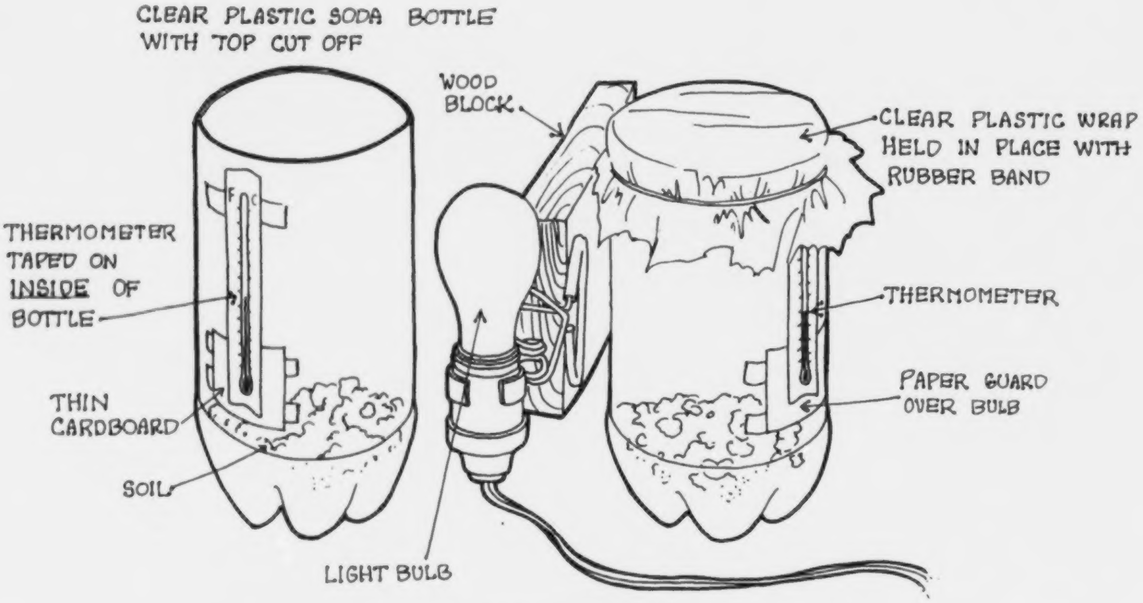
3. Close windows, window shades, and doors so that the classroom is free of drafts and direct sunlight.

4. Assemble the clip-on lights, bulbs and stands. Check that there are enough extension cords to reach the available outlets. Each bulb should be placed so it is standing upright between two bottles.

5. Tape the thermometers and cardboard strips inside the bottles as shown in the drawing. If the bottles still have labels attached, tape the thermometer just to one side of the label, on the inside of the bottle, so the label doesn't interfere with the experiment.

6. Using a cup to measure, put about 12 ounces of dry potting soil into each bottle.

7. Have one set of equipment near the front of the room to demonstrate how to set up the experiment.


CLEAR PLASTIC SODA BOTTLE WITH TOP CUT OFF
WOOD BLOCK
CLEAR PLASTIC WRAP HELD IN PLACE WITH RUBBER BAND
THERMOMETER TAPED ON INSIDE OF BOTTLE
THERMOMETER
PAPER GUARD OVER BULB
THIN CARDBOARD
SOIL
LIGHT BULB

THIS IS HOW EACH GROUP'S SETUP SHOULD LOOK AT THE START OF THE GREENHOUSE EXPERIMENT

Discuss The Homework

1. Invite the students to discuss their answers to each of the questions on the homework sheet. Emphasize that it is very difficult to determine whether the climate is changing, because of the variability in weather patterns from year to year.

2. Point out that in recent years, some ***climatologists*** (scientists who study climates) have begun to think that the climates in the world might be starting to change in a major way, due to human activity. They believe that the data the class looked at in the first session supports this idea.

3. Explain that one of the purposes of this unit is to give students background knowledge about the ***greenhouse effect,*** which some climatologists think may be causing the Earth to be warming up.

Why Do We Need a Model of the Atmosphere?

1. Point out that the atmosphere is a large and complex system, so experiments and measurements concerning it are difficult to perform.

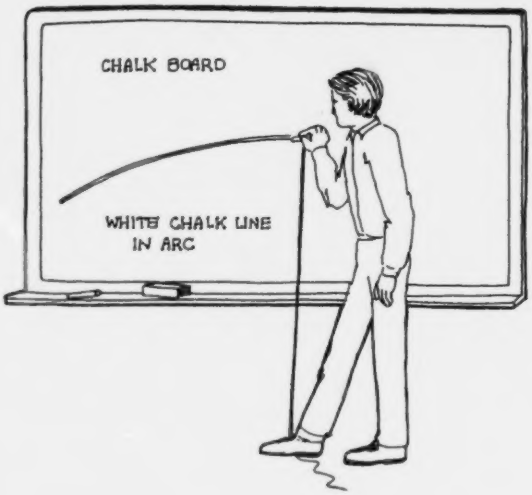
2. Ask the class to suggest experiments or ways of measuring the average temperature of the Earth's atmosphere. [Averaging lots of temperature measurements; finding places with long histories of records; analyzing data from isolated places, such as islands, that are less affected by other changes that can affect the climate.]

3. Ask what difficulties scientists might have in determining whether or not the average temperature of the Earth is heating up. [It is difficult to: find long-term historical data; regularly measure the temperature at sea and at the polar ice caps; distinguish long term changes in average temperature from short term variations; take into account differences in temperature between seasons and between places; and find locations that are unaffected by local factors, such as urban development and deforestation.]

4. Remind the students that the greenhouse effect and global warming are new areas of scientific study, and that scientists do not have all of the answers, partly because of the difficulties the class just discussed.

5. If your students have not already done so, point out that one way to test theories about climate change is to build a model of the atmosphere, and to experiment with the model. That's what the class will be doing this session.

6. Explain that before they begin to build their models, they need to have a clear idea of what the atmosphere is like.


CHALK BOARD
WHITE CHALK LINE IN ARC

How High Does the Atmosphere Go?

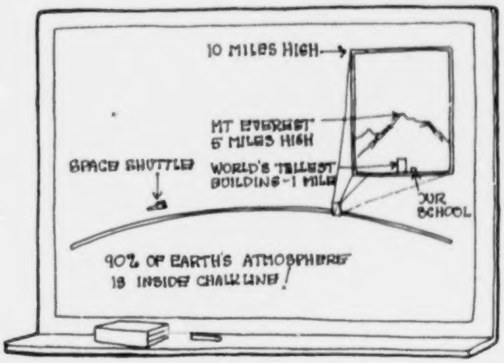
1. Tie a piece of chalk to a length of string. Standing next to the chalkboard, place your foot on the free end of the string, and draw an arc on the board, with a radius of about four feet. Tell your students that this arc represents the surface of the Earth.

2. Invite the students to suggest how far the Earth's atmosphere would extend above the surface in this drawing. [Students will probably suggest anywhere from two or three inches up to several feet.] Indicate their suggestions on the board, above the chalk-line.

3. Tell the students that scientists have found that over 90% of the Earth's atmosphere is within about 10 miles of the Earth's surface. The distance from the center of the Earth to its surface equals about 4,000 miles, and the scale of this drawing is about 1 foot = 1,000 miles. So, on this scale, 10 miles is about ⅛th of an inch, about as thick as a chalk-line. In other words, 90% of the Earth's atmosphere lies within the thickness of the chalk-line used to draw the Earth's surface!

4. Add that the space shuttle orbits well above the Earth's atmosphere. On the scale of the board drawing, the space shuttle would fly about 2" above the surface. (Draw a little space shuttle about 2" above the chalk-line.)

5. Explain that another way of understanding how far out the atmosphere extends is to imagine the Earth shrunk to the size of an apple. At that scale, the atmosphere is only the thickness of the skin of the apple.


10 MILES HIGH
MT EVEREST 5 MILES HIGH
SPACE SHUTTLE
WORLD'S TALLEST BUILDING - 1 MILE
OUR SCHOOL
90% OF EARTH'S ATMOSPHERE IS INSIDE CHALK LINE!

A Closer Look

1. Draw a rectangle around a small part of the curved line that represents the Earth's atmosphere, and explain that you are going to magnify that part about 200 times.

2. Draw another rectangle about two feet tall, with connecting lines to the smaller rectangle, showing it as an enlargement of that area. Label the base of the large rectangle: "the ground," and label the top: "10 miles high."

3. Ask the students, "How high is the tallest mountain in the world?" [Mt. Everest, over 29,000 feet, or over 5 miles above sea level] Draw a representation of Mt. Everest, with a peak a little more than halfway up the rectangle. Add other drawings to the rectangle, such as the world's tallest building [about one mile] and the height of the school (Ask: "Can our school be seen on this scale of 1 mile = 2.4 inches?")

4. Point out that exactly where the atmosphere ends is a debatable point. The lowest 7–10 miles is called the ***troposphere.*** The ***stratosphere*** goes up to about 30 miles. Together, the troposphere and stratosphere contain 99.9% of the air. (You may want to mention that the ozone is spread throughout the stratosphere, concentrated at a height of about 18—20 miles, which is called "the ozone layer." Emphasize that the "hole" in the ozone layer does not cause the greenhouse effect.)

5. Stress that most of the atmosphere is within the rectangle drawn on the board, and it gets thicker as you go down (as every mountain climber or high-flying pilot knows). Ask the class why it is that the atmosphere is thicker (denser) at the bottom—what holds it down? [gravity]

6. Tell the class that they are now going to make an experimental model of the atmosphere, and explore what happens when light shines on it.

The Greenhouse Experiment

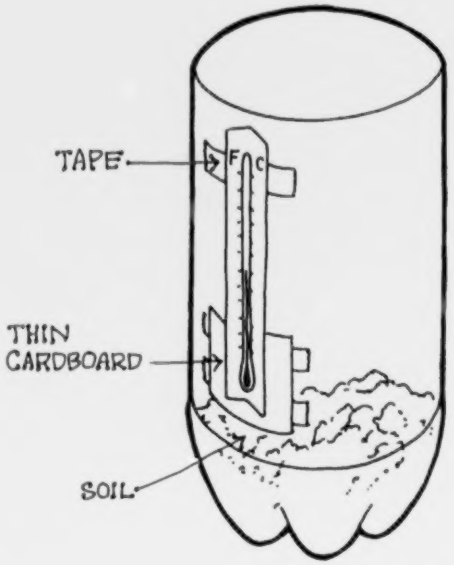
1. Assemble students into groups of four (or three). Do not distribute any equipment yet. Hold up a cut-off plastic soda bottle. Explain that the air in the bottles is going to "model" the Earth's atmosphere when it is exposed to rays from the Sun. Ask the class "What is going to model or represent the Sun?" [the light bulb]

2. Explain that because the experiment is going to measure the temperature of the air when exposed to the light rays, each bottle needs to have a thermometer inside. Hold up one of the bottles and point out:

   a. A thermometer is taped to the inside of the bottle, above the soil.

   b. The scale can be read through the plastic.

   c. The thermometer bulb is covered with paper to protect it from direct rays from the light bulb



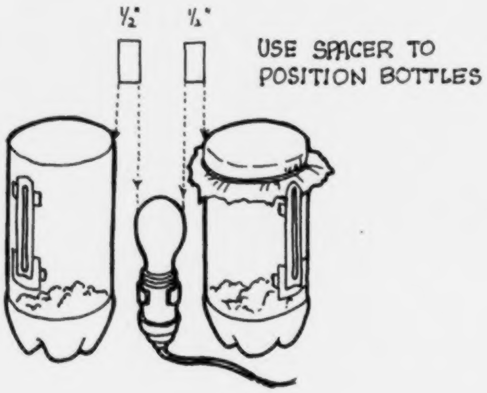
3. Explain that one of the bottles will be the "***control***," and nothing more will be done to it. Show the students how to put plastic wrap over the top of the second bottle by placing the plastic wrap tightly across the top, and securing it with a rubber band.

4. Pass out the equipment. Have each group cover one of the bottles with plastic wrap and secure it with a rubber band.

5. Obtain the students' undivided attention, and demonstrate how to set up the experiment:

   a. Arrange the bottles on either side of the light with thermometers facing outward, so they can be read easily.

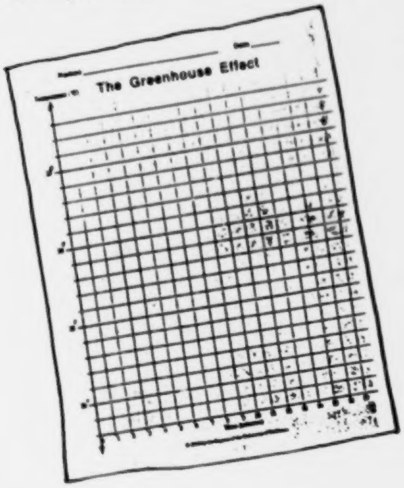
   b. Space the bottles equally distant from the light, using a half-inch strip of paper as a spacer. The light bulb should be turned off at this time.



6. Ask the students if they think the two thermometers should read the same or different temperatures at this time. [They should all show the same temperature—room temperature.] Have the students read the two thermometers. If they are different, explain that they must add degrees to the reading of the thermometer that gives a lower temperature, so they read the same at the start of the experiment. They will also need to add this number to each reading of the "lower" thermometer, as the experiment progresses. Tell them to write this number of degrees on a note next to that thermometer so they do not forget. This is called ***zeroing*** the thermometers.

If you notice that a team has set up an experiment near a draft or in direct sunlight, find a more sheltered area for that group's experiment.

7. Have students set up their experiments. Assist groups who are behind the others in setting up, so that all groups will be ready to start the experiment at the same time.



8. When all of the groups are ready to begin, ask that they listen carefully. Hold up the data sheet entitled "The Greenhouse Effect," and explain that this is what each group will use to record their results. Explain that two students will be in charge of one bottle and two students in charge of the other. One student (the observer) will read the thermometer and one student (the recorder) will use a *pencil* to record the data directly onto the graph paper.

9. Ask the students to vote on which bottle they think will get hotter, and by how much, when the light is turned on.

10. Hand out the data sheets (two per group) and pencils, at the same time checking each group's set-up.

Some of your students may become disappointed when the temperatures don't suddenly go up. Reassure them that there will be changes, but these could take a few minutes to become evident.

11. When you are sure that everyone is ready, explain that they will take a thermometer reading and record it with a pencil mark on their graph once every minute for 15 minutes. Have the students record the temperature (at time=0). Then begin the experiment by saying "Ready, Set, Go!" as they turn on their lightbulbs.

12. Call out the time each minute, for 15 minutes, or a few minutes longer if the temperatures in all bottles have not yet levelled off. Circulate to make sure the groups are recording the data correctly.

Analyze the Data

1. When the experiment is finished, tell each pair of students within each group to swap data with the other pair, and to copy this other set of data, in pencil, directly onto their graphing sheets as well. Tell them to label the graphs so that each pair has a result from a control bottle (uncovered) and an experimental bottle (covered).

2. Hand out red and green pens. Tell the students to draw a green line between dots for the control (open) bottle, and a red line between dots for the experimental (closed) bottle.

3. Have each group write, in large letters, the names of the members of the group on one of their completed graphing sheets. Collect one sheet from each group, and arrange them on the wall or board in a way that will allow the students to compare them easily.

4. Ask one student from each group to summarize what happened to the air temperature of the bottles in their experiment. Indicate which of the experimental results posted on the wall they are describing.

5. Ask the class to summarize what trends they see when they compare the experimental and control bottles. [In most cases students observe that in each bottle, the temperature increased, then levelled off, and at the end of the experiment, the open bottle is cooler than the closed bottle.]

If it is a very hot day, there may not be a large difference between the air temperature in the closed bottle and the open bottle. In any case, it is not essential for the experiments to come out exactly as you expect. Encourage the students to discuss what they actually observe.

6. Ask a series of questions to help the students explain the results of their experiments in their own words:

   - Why did the temperature in each of the bottles go up? [Both light and heat from the bulb passed through the plastic and warmed the air and soil inside the bottle.]

- Why did the temperature of both bottles level off? [Heat from the light bulb can get out as well as in. To see this, turn off the light bulb and hold your hand behind the bottle. You will feel heat coming out.]

- Why did the temperature of the closed bottles level off at a higher temperature than the open bottles? [The air inside both bottles is heated. The warm air in the open bottle mixes with cooler air outside, while the warm air in the closed bottle is trapped by the plastic top.]

Understanding the Greenhouse Effect

1. Explain to the students that the point at which temperature levels off is called ***the equilibrium temperature.*** It is called that because the flow of energy into the bottle just equals the flow out of the bottle. **Ask the students, "What difference did you measure between the equilibrium temperatures of the experimental and control bottles?"**

2. Ask the students to tell you what happens on a hot day in a car parked in the sun with the windows shut. [It gets very hot.] Does the temperature keep going up as long as the Sun shines? [No, it levels off at a higher temperature.] How do you cool the car down? [By opening the windows] Why does that work? [Because the hot air can get out, and cool air can get in]

3. Explain that this phenomenon of heat being trapped, as it was inside their closed and partly-closed bottles, is called ***the greenhouse effect.*** It is called this because greenhouse buildings, made of glass and used for growing plants, trap warm air in the same way.

4. Remind the students that the purpose of the experiment was to make a model of the atmosphere, and explore what happens when light shines on it. Ask them to relate their model to the real world, using questions such as the following:

- How did the equipment used in this experiment **correspond to the real Earth?** [The bulb was similar to the Sun; the air represented the atmosphere; and the soil was like the Earth.]

- How did the sample of air inside the bottles behave in a way that is **similar to the Earth's atmosphere?** [The air heated up when exposed to heat and light from the Sun, and finally leveled off at a certain equilibrium temperature.]

- What things were **different between this experiment and the real Earth's atmosphere?** [The Earth's atmosphere does not have any solid barriers, like the plastic.]

5. Conclude by explaining that scientists think that something is trapping heat in the earth's atmosphere, causing the temperature to go up. However, it is *not* a solid barrier like the plastic. What *is* causing the greenhouse effect in the atmosphere? You'll find out in the next session.

Some students might suggest that the open bottle represents the "hole" in the ozone layer. If this comes up, ask the students what they think would happen to the temperature if you poked a hole in the plastic cover [The temperature would go down.] Emphasize that the thinning of the ozone layer is **not** *a major cause of global warming. It may, in fact, contribute to cooling.*

An extension of this activity is to do the experiment again, but with bottles partially closed rather than completely closed. To get observable differences we suggest you compare an open bottle with experimental bottles that are half covered, three quarters covered, and fully covered.

Another extension would be to conduct the experiment near the window, placing the thermometers inside the glass jars.

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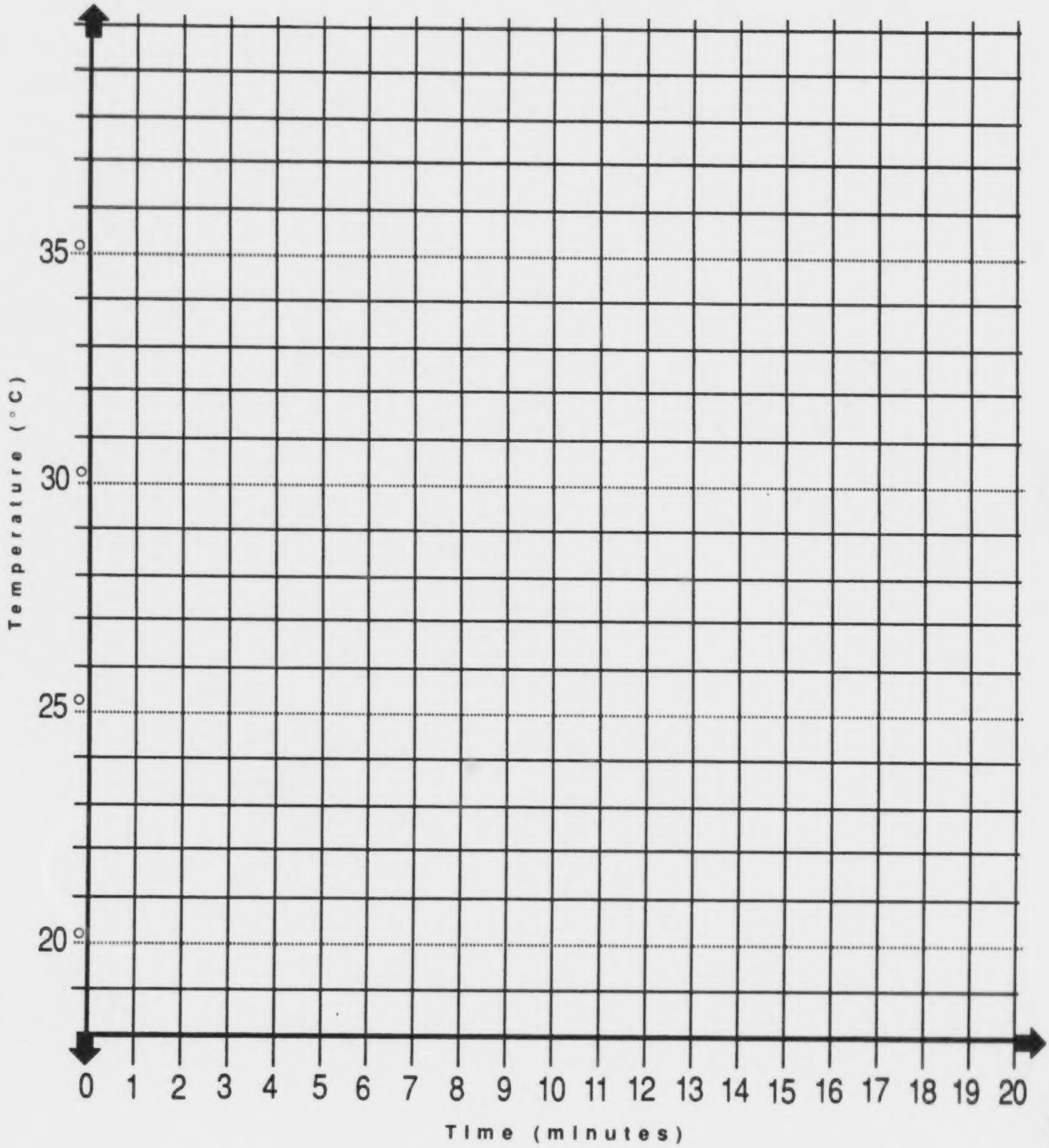
Names________________________ Date ________

The Greenhouse Effect



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1. Global Warming

What do a car idling in city traffic and a smokestack on an electric power plant have in common with rice plants standing in a wet Chinese field and a herd of cattle on South American rangelands? Although this riddle may seem difficult, the answer will be clear after studying this lesson.

The Earth's atmosphere is a thin blanket of gases. It traps the Earth's warmth and makes our planet liveable. But the atmosphere that we take for granted is changing. Human activities are releasing gases that threaten to intensify the heat-trapping properties of the atmosphere. There is growing concern about the potential effects of these atmospheric changes.

This lesson is based on Chapters 2, "Climate Change: A Global Concern," and 9, "Energy." References are given to additional materials including Chapter 24, "Atmosphere and Climate." The lesson begins with facts about changes in the Earth's atmosphere and continues with theories about possible climate changes. A variety of materials are provided to help students analyze how human activities, especially the use of energy, contribute to the warming potential of the atmosphere. Using a "Greenhouse Index," students identify leading contributors to atmospheric changes. The lesson concludes by describing strategies for dealing with the threat of significant climate change.

Objectives

By the time they finish this lesson, students should be able to:

- Identify the major "greenhouse gases."
- Identify human activities that are changing the Earth's atmosphere.
- Communicate reasons why there is concern that the Earth's climate may change.
- Identify major contributors to global warming.
- Explain why greenhouse gases are a global problem.
- Identify lifestyle/local strategies for dealing with potential global warming.
- Identify national/international strategies for dealing with potential global warming.

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GREENHOUSE EFFECT

1. Global Warming

Teaching Strategies

This lesson is divided into seven parts. Because the subject is complex, you will need two class periods or more if you wish to pursue any of the topics in greater detail or add activities.

The lesson includes the following materials that may be duplicated. The following are designed as student handouts:

1.1 Facts About Global Warming
1.2 How the Greenhouse Effect Works
1.3 Facts About Energy Use
1.4 How Five Countries Contributed to the Greenhouse Heating Effect
1.5 Cutting Energy Use and Carbon Emissions

The following can be used to make transparencies for an overhead projector:

1.1 Contributions to Global Warming
1.2 Annual Additions of Three Major Greenhouse Gases to the Atmosphere, 1957-87
1.3 Long-Term Variations of Global Temperature and Atmospheric Carbon Dioxide
1.4 Greenhouse Index: 10 Countries with the Most Greenhouse Emissions, 1987
1.5 Trends in Energy Intensity in Developed Countries, 1973-87

You may wish to add additional resources from the book using the suggestions in the margin at various points in the lesson.

Beginning the Lesson

The first part of the lesson defines the "greenhouse effect," identifies the "greenhouse gases" and their sources, and describes changes in the atmosphere.

Write the following on the chalkboard:

See Status of Current Knowledge, pp. 12-13.

FACT: Gases in the atmosphere have a "greenhouse effect"--they trap heat and keep the Earth warmer than it would be otherwise.

Distribute copies of **Handout 1.1, "Facts About Global Warming."** Help students identify five greenhouse gases and their sources. (Water vapor, another greenhouse gas, is not shown on the sheet.) It's important for students to realize that the "greenhouse effect" has kept the planet about 60 F (33 C) warmer than it otherwise would be. Without this warming effect, the Earth would be too cold to support life.

Show a transparency made from **Master 1.1, "Contributions to Global Warming."** The graph on the left shows how much each gas contributes to global warming. The graph on the right shows how various human activities contribute to global warming. The largest

Teaching Strategies

See Box 2.1, Estimating Responsibility for Potential Climate Change, p. 16.

category, "Energy," includes production and use of energy from fossil fuels--for example, electric power production and motor vehicle emissions. Industrial activities produce greenhouse gases by burning fossil fuels such as coal and by creating synthetic compounds such as chlorofluorocarbons. Deforestation releases large amounts of carbon dioxide because carbon stored in trees and plants is released into the atmosphere when forests are cleared and burned. Agricultural activities also release greenhouse gases: flooded rice paddies are a source of methane emitted by anaerobic bacteria, and nitrous oxide is produced by bacterial action on chemical fertilizers.

Point out that human activities are not the only sources of greenhouse gases. There are natural sources. Animals and plants exhale carbon dioxide. Swamps, marshes, and tundra are sources of methane. There are also natural processes for absorbing these gases from the atmosphere. Carbon dioxide is absorbed in the oceans and in the soils and is taken in by plants during photosynthesis. Methane is decomposed by chemical processes in the atmosphere.

Write the following statement on the chalkboard:

FACT: Concentrations of greenhouse gases are increasing rapidly.

Show a transparency made from **Master 1.2, "Annual Additions of Three Major Greenhouse Gases to the Atmosphere, 1957-87."** This graph shows additions of carbon dioxide, methane, and CFCs (the warming potential of methane and CFCs is expressed in terms of carbon dioxide heating equivalents).

Explain that the graph shows *additions*, not *emissions*. Additions of carbon dioxide and methane are estimated by subtracting from the emissions, estimates of the carbon dioxide and methane absorbed by natural processes (as mentioned above). There are no natural "sinks" for CFCs since these are synthetic compounds.

The graph shows a significant increase. In 1987, the world was adding to the warming potential of the atmosphere at three times the rate of 1957. **Handout 1.2, "How the Greenhouse Effect Works,"** explains that although the greenhouse effect is a natural process, increasing emissions of greenhouse gases can create a problem. By 1988, the level of carbon dioxide in the atmosphere was 20-25 percent higher than any other time in the past 160,000 years. CFC levels are growing at 5 percent a year. Methane levels are much higher than ever before and are growing at 1 percent annually. The three gases vary in their heat-absorbing potential. Adding a molecule of methane will trap 20-30 times as much heat as a molecule of carbon dioxide; adding a CFC molecule will trap 20,000 times as much heat as a carbon dioxide molecule.

Teaching Strategies

Ask: *Why are more and more greenhouse gases being emitted?* The population of the world is increasing. More and more people are using energy, by driving cars for example. Increasing use of fossil fuels has been part of the process of development and industrialization. Deforestation is in part caused by pressure to meet the needs of the increasing population. (For additional material on deforestation, see Lesson 2, "Deforestation and Biodiversity," and Lesson 6, "The Economics of Natural Resources.")

Identifying Reasons for Concern about Atmospheric Changes

Write the following on the chalkboard:

THEORY: Continued greenhouse gas emissions will lead to global warming.

No one knows what the effects will be of adding such quantities of greenhouse gases to the atmosphere. One theory is that the Earth's climate will grow warmer unless other climatic mechanisms counteract the warming. Predictions of possible climate change are based in part on long-term studies of the concentrations of carbon dioxide in the atmosphere.

See State of the Science, pp. 18-24.

Show a transparency made from **Master 1.3, "Long-Term Variations of Global Temperature and Atmospheric Carbon Dioxide."** Explain that data in the graph is based on analysis of an ice sample taken by Russian scientists at Vostok Station in East Antarctica. The ice sample, a core over one mile long, contained ice formed 160,000 years ago. Bubbles in the ice contained samples of the atmosphere.

The graph reveals that changes in greenhouse gas concentrations are closely correlated with changes in the Earth's surface temperature. As carbon dioxide levels have risen, the global climate has warmed. Lower atmospheric levels of carbon dioxide have coincided with periods of global cooling. The low points on the graph indicate ice ages.

Using data such as this, scientists have made computer models to try to predict whether global warming will take place. There are a number of unknowns, such as:

See pp. 20-24 for a discussion of climate models.

- How the dynamics of the ocean will be affected.
- How cloud behavior will affect the climate.
- How living systems will respond to global warming and what influence they will have on the climate.

Teaching Strategies

Predicting Possible Effects of Global Warming

Discuss the possible effects of rapid and significant global warming. Can students suggest any possible changes? How might warming affect agriculture, for example? Among the possibilities are the following:

For maps showing possible effects of climate change on summer temperatures and soil moisture, see p. 21.

HEALTH: People in the U.S. might be at risk for tropical mosquito-borne diseases such as malaria, dengue fever, and yellow fever.

For a discussion of the impact of climate change on human health, see pp. 62-63.

AGRICULTURE: The growing season in northern areas such as Finland, Japan, Iceland, and Canada would be lengthened. Yields of wheat, corn, and soybeans in the United States might decrease.

The effects of climate change on agriculture are discussed on pp. 95-98.

FORESTS: Forests pests would thrive. Parasites from the tropics might attack temperate forests. Many U.S. hardwood species could survive only in the northern United States or Canada.

Pages 109-113 discuss possible effects of global warming on forests and rangelands.

RANGELANDS: An ongoing decline in productivity from drought and erosion would intensify. Increased fires would be a problem.

WILDLIFE: Many species would become extinct because their habitats would shift, shrink, or disappear.

See Focus on Greenhouse Warming and Biodiversity, pp. 130-134.

OCEANS: Locations of currents and fishery areas could change. Coastal areas could be flooded by rising sea levels. Low-lying countries such as Bangladesh would be threatened.

See Effects of Climate Change on Oceans and Coasts, pp. 195-196. Chapter 13, Global Systems and Cycles, discusses global climate monitoring and global climate models.

Emphasize that it is not possible to make reliable predictions about the impact of climate change, particularly at regional levels. Scientists do not know enough about Earth's climatic cycles.

Assigning Responsibility for Greenhouse Gas Emissions

Ask: *Which countries are responsible for adding the most greenhouse gases to the atmosphere?* Have each student quickly list the countries he or she believes emit the most gases.

Show a transparency made from **Master 1.4, "Greenhouse Index: 10 Countries with the Most Greenhouse Emissions, 1987."** (Note: the European Community comprises 12 countries--Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, United Kingdom. Myanmar was formerly Burma.)

Compare the countries listed on the graph with students' lists. Are students surprised that some of the countries are in the "Top 10?"

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Teaching Strategies

Ask, *Which of the "Top 10" are developed countries?* (the United States, the European Community, U.S.S.R., Japan, and Canada)

Which of the "Top 10" are developing countries? (Brazil, China, India, Indonesia, Mexico)

The top 50 countries with the highest greenhouse gas emissions are listed on p. 15.

Ask students to suggest reasons why these countries are the "Top 10." What are the likely sources of greenhouse gas emissions in developed countries? In developing countries?

Also see Table 2.3, Per Capita Greenhouse Index, p. 17, and Figure 2.5, Net Greenhouse Gas Emissions per U.S. Dollar of Gross National Product, 1987, p. 19.

Emphasize that both developed and developing countries contribute to greenhouse gases emissions. However, the sources of gases differ somewhat as do the amounts of gases released.

Examining Energy Use

For a discussion of the global carbon cycle and statistics on deforestation as a source of atmospheric carbon dioxide, see pp. 109-110.

Distribute copies of **Handout 1.3, "Facts About Energy Use,"** and **Handout 1.4, "How Five Countries Contributed to the Greenhouse Heating Effect."**

The first is a brief outline of energy use in developed and developing countries. The second is a detailed look at the five countries that, in 1987, contributed 50 percent of the warming potential. One way to analyze the information in this table is to ask students to rank the countries in each category. For example, the ranking for emissions from burning coal is 1, China; 2, United States; 3, U.S.S.R.; 4, India; 5, Brazil. The ranking for livestock is 1, India; 2, U.S.S.R.; 3, Brazil; 4, United States; and 5, China. A series of rankings helps to illustrate the differences between developed and developing countries.

Another way to analyze the information is to have students make graphs. If you wish to add data from other countries, see Table 24.2, pp. 348-349.

In comparing and contrasting energy use in developed and developing countries, point out that attempts to control greenhouse gases must take into account the rising energy demands of the developing countries. The graph, **"World Consumption of Energy, 1970-88," Handout 1.3,** shows a steady increase in consumption of energy in developing countries. However, evidence now suggests that economic growth is not tied inexorably to increased energy consumption, as was once thought.

See Energy Efficiency at the Crossroads, pp. 145-147.

Show a transparency made from **Master 1.5, "Trends in Energy**

Intensity in Developed Countries, 1973-87." The graph contrasts three groups of developed countries: those in North America (Canada and the United States), those in Europe, and those in the Pacific (Japan, Australia, and New Zealand). The countries are compared in terms of energy intensity--the amount of energy used to produce a unit of gross domestic product (GDP).

The graph shows that by 1987, all three groups of countries had reduced their energy intensity. Another way of saying this is that the countries had become more energy-efficient by using energy conservation strategies. For example, the government of Japan, following the oil shocks of the 1970s, adopted a national policy of reducing dependence on oil. This policy caused industries and utilities to increase their efficiency, thus lowering fuel consumption. Japan is now the world's leader in industrial energy efficiency. Unfortunately, as oil prices fell in the late 1980s, some developed countries, including the United States, became less energy efficient.

In developing countries, energy planning has focused primarily on expanding conventional energy supplies rather than on improving energy efficiency. Energy intensity in most countries has risen steadily.

For examples of energy conservation in developing countries, see pp. 76-77.

A recent study published by the World Resources Institute suggests that an energy strategy based on increased efficiency can sustain economic growth in both developing and developed countries. (See José Goldemberg, *et.al*, *Energy for a Sustainable World*, World Resources Institute, Washington D.C., 1987.)

With some help from the industrialized world, developing countries could apply technical energy-efficient solutions to promote economic growth while keeping energy demand relatively low. The necessary technologies are either commercially available or will be soon. But it would take large amounts of capital and skilled management to put these technologies to use.

Identifying Strategies to Deal with Global Warming

In discussing the possible strategies, there are several general points to keep in mind:

- Virtually all elements of human activity contribute to greenhouse gas emissions.
- Atmospheric degradation is a global problem. It doesn't matter where the gases are emitted; the atmosphere mixes them thoroughly.

GREENHOUSE EFFECT

1. Global Warming

Teaching Strategies

No one country or region can, by itself, prevent the buildup of greenhouse gases. Dealing with the problem will require a high degree of political consensus and cooperation.

Global warming is linked with other serious environmental problems, particularly acid precipitation, urban smog, and depletion of the stratospheric ozone layer.

Atmospheric change is an invisible process. People, and nations, tend to react to events, rather than processes. A recent survey by the Roper Organization, Inc. revealed that those Americans interviewed ranked global warming 15th out of 19 environmental problems. (The problems ranked as most serious were water pollution from manufacturing plants, oil spills, hazardous-waste releases, and industrial air pollution. In contrast, a 1990 report by the U.S. Environmental Protection Agency listed as the top four problems: global climate change, habitat destruction, species extinction, and ozone-layer depletion.)

Divide students into small groups. Ask them to spend about 15 minutes developing a few specific recommendations for dealing with potential global warming. Remind them that the handouts contain helpful information.

Ask each group to share its ideas. Organize the various ideas by writing them on the chalkboard under three headings:

PREVENTION MITIGATION ADAPTATION

Note: These are three basic policy options that can be used to address global warming:

See Policy Options Available to Address Global Warming, pp. 24-30.

PREVENTION--Preventing greenhouse gases from being released.

One example of this is the international action taken to phase out production of CFCs. The Montreal Protocol on Substances that Deplete the Ozone Layer, which took effect in 1989, was an agreement by 56 nations to cut the use of CFCs by 1996. In 1990, more than 70 countries agreed to phase out CFCs by the year 2000. Germany, Australia, and the Scandinavian countries are aiming to eliminate their use of CFCs even earlier, by 1997.

Similar international negotiations are expected to take place regarding global warming. The United Nations Environment Programme, which helped put together the Montreal Protocol, hopes to achieve an agreement on global warming in the next few years. This agreement, however, will be more difficult because it asks nations to limit their energy use--a much more vital need than CFCs, a chemical refrigerant and propellant.

The most promising prevention strategy is to achieve increased efficiency in producing and using energy. For example, replacing a single 75-watt incandescent bulb with an 18-watt fluorescent bulb provides the same light but prevents the emission of over 200 pounds (100 kilograms) of carbon over the life of the new bulb.

Other prevention techniques include:

- Switching to less carbon-intensive fuels (coal produces about 80 percent more CO_2 per unit of energy as natural gas and 1.25 times as much as oil).
- Using carbon-free energy sources.
- Slowing deforestation.
- Altering agricultural practices (developing new strains of rice that don't need flooding, enclosing manure piles and feedlots to capture methane).

MITIGATION--Compensating for emissions that occur.

Reforestation is an example. For example, a United States independent power producer, Applied Energy Services (AES), built a new 183-megawatt coal-fired powerplant in Connecticut which is estimated to release approximately 16.5 million tons (15 million metric tons) of carbon in the form of dioxide during the plant's lifetime. To compensate for this, AES is funding a forestry and farming project to plant 52 million fast-growing trees in Guatemala.

See Agroforestry in Guatemala to Offset Carbon Releases in the United States, p. 111.

This project is an example of one way to compensate for carbon emissions into the atmosphere. However, from both an ecological and an economic standpoint, it would be less expensive and better to slow deforestation and manage national forests, rather than clearing forests and then replanting them.

ADAPTATION--Helping communities and nations adapt to changes in climate and their consequences.

Animal species would be likely to migrate in response to climate change. To adapt, wildlife conservation techniques would have to be modified for a warmer climate. Today's basic concepts of nature-reserve management, such as wilderness, might become obsolete. Corridors to allow species to migrate might be needed between protected areas.

Teaching Strategies

In agriculture, new, improved plants would be needed to cope with hotter temperatures and more difficult growing conditions.

The U.S. Army Corps of Engineers has already begun studying ways to protect low-lying cities such as Charleston, South Carolina and New Orleans, Louisiana from rising sea levels by constructing dikes around the cities.

Concluding the Lesson

Ask students to summarize the important facts about the greenhouse effect and changes that are taking place in the atmosphere. Then, ask them to summarize the theories about what might happen as a result of increasing levels of greenhouse gases. What is known and what is still unknown?

Point out that there is a choice. We can wait until we know more about the nature and timing of climate change. Or we can recognize that global climate change would be an unparalleled threat to human and natural systems and do whatever we can to prevent, reduce or mitigate human impact on the atmosphere. Technological and policy decisions made (or not made) by nations now will substantially affect the timing and severity of any global warming that occurs.

Students also have a choice because by using energy, they contribute "greenhouse gases" to the atmosphere. For example, watching five hours of television results in the emission of one pound of carbon. Using a 1500-watt hair dryer for one hour results in the emission of one pound of carbon.

Write the following on the chalkboard:

11,000 pounds of carbon

This number represents current yearly per capita carbon emissions in the United States. Much of this comes from industry, but about one-third of the energy consumed in the United States is used by individuals in their homes and cars.

Note: To compare per capita carbon emissions in the United States with those of other countries, do the following:

- See **Table 24.1, Sources of Current Greenhouse Gas Emissions**, pp. 346-347. Look under the heading "Anthropogenic Additions to the Carbon Dioxide Flux" and find the column titled Per Capita (metric tons). Locate the figure for a specific country.

- To convert this figure to pounds: first multiply the per capita figure (metric tons) by 1.102 (converts metric tons to short tons), then multiply by 2,000 (converts short tons to pounds). This figure is the per capita carbon emissions expressed in pounds.

Students can choose to reduce their own contribution to atmospheric changes. There are many ways they can cut down on their use of electricity and gasoline.

Distribute copies of **Handout 1.5, "Cutting Energy Use and Carbon Emissions,"** and discuss the suggestions for saving energy. Which actions would reduce carbon emissions the most? Which actions do students think might be feasible for them and their families?

Can students suggest other ways they can save energy? There are many possibilities including recycling, using alternatives to gas or electric applicances (hand tools instead of power ones, drying clothes outside on a line instead of in a dryer), walking or bicycling instead of driving, etc. **Activity 1.2, Keep an Energy Diary**, will help students take a close look at the ways in which they use energy. This activity may help them identify ways in which they are willing to alter their lifestyle in order to reduce energy consumption.

Suggestions for Further Reading

- World Resources Institute (WRI), *The Greenhouse Trap* (Beacon Press, Boston, 1990).
- World Resources Institute, *Changing Climate: A Guide to the Greenhouse Effect* (World Resources Institute, Washington, DC, 1989).
- Jonathan Weiner, *The Next One Hundred Years* (Bantam Books, New York, 1990).
- *The Challenge of Global Warming*, Dean Edwin Abrahamson, ed. (Island Press, Washington, DC, 1989).
- American Council for an Energy Efficient Economy (ACEEE), *The Most Energy Efficient Appliances* (ACEEE, Washington, DC, 1988).
- Wallace Broecker, "The Biggest Chill," *Natural History*, Vol. 96, No. 10, October 1987, pp. 74-82.
- Christopher Flavin, "The Heat Is On," *Worldwatch Magazine*, November/December 1988, pp. 10-20.
- José Goldemberg, *et al. Energy for a Sustainable World* (World Resources Institute, Washington, DC, 1987).
- John Gribbon, *The Hole in the Sky* (Bantam Books, New York, 1988).
- Richard Kerr, "The Global Warming is Real," *Science*, Vol. 243, No. 4891 (February 3, 1989), p. 603.
- Gordon MacDonald, *Climate Change and Acid Rain* (Mitre Corporation, McLean, VA, 1986).
- Sheila Machado and Rick Piltz, *Reducing the Rate of Global Warming: The States' Role* (Renew America, Washington, DC, 1988).
- James J. MacKenzie, *Breathing Easier: Taking Action on Climate Change, Air Pollution, and Energy Insecurity* (World Resources Institute, Washington, DC, 1988).
- Joan M. Ogden and Robert H. Williams, *Solar Hydrogen: Moving Beyond Fossil Fuels* (World Resources Institute, Washington, DC, 1989).
- Michael Renner, *Rethinking the Role of the Automobile*, Worldwatch Paper 85 (Worldwatch Institute, Washington, DC, 1988).
- *Scientific American*, Special Issue on Energy, Vol. 263, No. 3, September, 1990.
- Stephen Schneider and Randi Londer, *The Coevolution of Climate and Life* (Sierra Books, San Francisco, 1984).
- United Nations Environment Programme (UNEP), *The Greenhouse Gases*, UNEP/GEMS (Global Environmental Monitoring System) Environment Library No. 1 (UNEP, Nairobi, 1987).
- UNEP, *The Ozone Layer*, UNEP/GEMS Environment Library No. 2 (UNEP, Nairobi, 1987).

Student Enrichment Activities

See pp. viii, ix, and x for Skills Emphasis key.

1.1 Role Play: International Greenhouse Gas Negotiations

Over the next few years, developed and developing countries will attempt to reach an international agreement on limiting greenhouse gases. Students can role play these negotiations in the classroom by taking the positions of different countries. Many European countries have indicated a willingness to limit greenhouse gases, the United States has resisted for fear limiting energy use might slow the economy. Many developing nations insist on aid from developed countries to help them limit deforestation and transfer to more energy efficient technologies. For a more realistic experience with international negotiations, your school can simulate this role-play via computer with other schools in the United States, Europe, and Japan. The International Communication and Negotiations Simulations (ICONS) simulates negotiations on environmental human rights, arms race, and social issues. For a free brochure, contact Patty Landis, ICONS, University of Maryland, College Park, MD 20740, (301) 405-4171.

Skills emphasis: *Environmental Education 1, 3, 7; Social Studies 2, 4, 5, 6, 7, 8.*
Suggested for use in: *Political Science, Contemporary Issues, Environmental Issues.*

1.2 Keep an Energy Diary

About 11,000 pounds of carbon or its heating equivalent are added to the atmosphere each year for each person in the United States. To help students identify ways in which their activities contribute carbon emissions, have them keep a record of their energy use for one day. For example, they should record appliances used (radio or TV, toaster, hair dryer), hours of using electric lights, miles driven in a car (burning a single tank of gasoline produces 300-400 pounds of carbon dioxide, the most important greenhouse gas), etc. To help students identify ways in which their use of energy contributes to carbon emissions, have them keep a record of their energy use for one day. For example, they should record the appliances they use (radio or TV, toaster, hair dryer, etc.) and the amount of time the appliance is used, the length of time they use electric lights, how many miles they drive or are driven in a car (burning a single tank of gasoline produces 300-400 pounds of carbon dioxide, the most important greenhouse gas), etc. Once they have recorded their energy use, students should analyze it. In what ways could they save energy? (See **Handout 1.5, "Cutting Energy Use and Carbon Emissions."**) What changes are they willing to make in order to save energy? Will any of these changes cost money? Will any of them save money?

Skills emphasis: *Environmental Education 3,4; Science 8, 9; Social Studies 1, 2, 5.*
Suggested for use in: *Social Studies, Environmental Education.*

1.3 Identify Energy-Saving Programs

What is being done by government, business, and private groups in your community to develop energy-saving programs? If local utility companies are working to promote energy efficiency, collect information about these programs. Are there any voluntary or mandatory recycling programs? (Saving energy is one benefit of recycling--processing recycled newspapers uses less energy than processing raw pulp, for example.) Are there ride-sharing or vanpool programs for commuters?

Skills emphasis: *Environmental Education 5, 7; Social Studies 1, 4, 6.*
Suggested for use in: *Social Studies, Environmental Issues.*

1.4 Shop for an Appliance

A major way families can conserve energy in the future is to select new appliances based on their energy efficiency as well as on other features. Large appliances such as refrigerators, air conditioners, and dishwashers are required to have labels showing the yearly operating costs (based on estimated costs for electricity or gas). Have students choose an appliance and compare operating costs. For example, how do yearly energy costs vary for different models of an 18 cubic foot refrigerator? Also, calculate whether the costs on the labels would be accurate for your area (find out the local cost per kilowatt hour from your electric power company). Use the Energyguide label (see **Handout 1.5**) to determine the number of kilowatt hours needed to operate different models or different sizes of refrigerators. To do this, divide the estimated yearly energy cost of the model by 8.04 cents (the price per kilowatt hour used to calculate the yearly energy cost). To calculate the carbon output from operating a refrigerator, multiply the kilowatt hours by 0.4. That will give the carbon output in pounds.

Student Enrichment Activities

Skills emphasis: *Environmental Education 1, 3, 4, 6; Science 1, 2, 3, 8, 9; Social Studies 5, 6.*
Suggested for use in: *Social Studies, Math, Home Economics.*

1.5 Analyze Advertisements

Recently, a number of companies have addressed environmental issues in their advertisements. The ads tend to show how a company is working to help the environment or how a product is "friendly" to the environment. Ads by energy companies are especially interesting. Collect samples of such advertisements. Business publications such as *The Wall Street Journal* are a good place to look. Analyze the text and the pictures in the ads to determine both the message and the image of the company or product. Are these ads simply using people's concern with the environment as a way to sell their products? Or are they actually improving an old product or presenting a new one that is more environmentally benign? Investigate the claims made in the ad by writing the company for more information and by researching the issue through other sources.

Skills emphasis: *Environmental Education 3, 5; Science 5; Social Studies 6.*
Suggested for use in: *Environmental Issues, Social Studies.*

1.6 Study Alternative Sources of Energy

Many types of non-fossil energy sources are already in use: solar-thermal heating, solar-thermal power, wind energy, and geothermal heat. Have students choose one of these energy sources and research the question: Can alternative sources of energy provide a significant percentage of our energy needs in the next 25 years? Where are these sources being used? Are there any problems in using these types of energy? What are the costs? (Also see Nancy Radar Critical Mass Energy Project, Public Citizen, *The Power of the States: A Fifty State Survey of Renewable Energy*, (Public Citizen, Washington, DC, 1990). Photovoltaic power may become important in the future. Also, a new generation of advanced nuclear technologies may become important if the problems of safety and radioactive wastes can be solved. For a start in researching these technologies, see pp. 152-156 of *World Resources 1990-91*.

Skills emphasis: *Environmental Education 5, 6; Science 5; Social Studies 6.*
Suggested for use in: *Chemistry, Environmental Issues, Earth Science.*

1.7 Plant a Tree

Trees planted in an urban area not only take up carbon dioxide but shade buildings in hot weather and shield them from winds in cold weather, reducing air conditioning and heating demands--and thus electricity generation, much of which comes from burning fossil fuels. A single tree can absorb 36 pounds of carbon per year from the air. Encourage students, either individually or as a group, to identify places where trees could be planted. Do research to find out what types of trees are appropriate and what type of care the trees require. If possible, students should plant and care for trees, either at home, or at school. The American Forestry Association has a "Global Releaf" program. For a free fact sheet on launching a tree-planting campaign, write the Trust for Public Land, 116 New Montgomery, 4th Floor, San Francisco, CA 94105. Ask for *Step-by-Step Guide to Organizing a Releaf Effort.*

Skills emphasis: *Environmental Education 7, 8, 9; Social Studies 4, 8.*
Suggested for use in: *Biology, Ecology, Environmental Science, Earth Science.*

Audiovisual Resources

- Green Energy, VHS, 26 min., Films for the Humanities and Sciences. Biological products like wood chips, corn, and garbage, can be an alternative to petroleum.
- The Heat is On: The Effects of Global Warming, VHS, 26 min., Films for the Humanities and Sciences.
- *The Home Energy Conservation Series*, VHS, 3 films: 16 min., 28 min., 28 min., Bullfrog Films and Rodale Press. *1) Opening Your Home to Solar Energy, 2) Wood Heat, 3) How to Keep Heat in Your House.*
- *Lovins on the Soft Path: An Energy Future with a Future*, VHS, 36 min. (includes a 33 page study guide), Bullfrog Films. *Amory Lovins is the foremost proponent of an energy policy that concentrates on efficiency and appropriate use of renewable resources.*
- *Race to Save the Planet* series, three episodes: "Only One Atmosphere," "Now or Never," and "More or Less," VHS, 60 min. each. WGBH Boston, call 1-800-LEARNER (California) to order.
- *Running Out of Steam*, VHS, 26 min., Bullfrog Films. *Who benefits from present energy policies? Energy efficiency and renewables could create more jobs and warmer homes.*

See p. 126 for addresses of video distributors.

GREENHOUSE EFFECT

1. Global Warming

1.1 Facts about Global Warming

The Earth's atmosphere, a thin blanket of gases, serves many important functions. One is to protect the planet from the harshest of the sun's ultraviolet radiation. Another is to trap Earth's warmth to keep rivers and oceans from freezing--what is called the "greenhouse effect." Carbon dioxide and water vapor are the most important gases in creating the insulating effect of the atmosphere.

The amount of carbon dioxide in the atmosphere has been increasing rapidly. Human activities are also releasing other "greenhouse" gases such as methane and chlorofluorocarbons, that intensify the heat-trapping properties of the atmosphere as a whole. Chlorofluorocarbons also rise into the upper layer of the atmosphere, the stratosphere, where they destroy the protective layer of ozone, a gas that forms a shield against ultraviolet rays that can harm many forms of life.

There is growing concern about the effects of these atmospheric changes which could bring on rapid and profound changes in climate.

Sources and Types of Most Important Greenhouse Gases

CARBON DIOXIDE (CO_2): released by burning of fossil fuel (oil, coal, and natural gas), flaring of natural gas, changes in land use (deforestation, burning and clearing land for agricultural purposes), and the manufacturing of cement accounts for half of warming potential caused by human activity.

METHANE (CH_4): sources include landfills, wetlands and bogs, domestic livestock, coal mining, wet rice growing, natural gas pipeline leaks, biomass burning, and termites. Molecule for molecule, it traps heat 20-30 times more efficiently than CO_2. Within 50 years it could become the most significant greenhouse gas.

CHLOROFLUOROCARBONS (CFCs): industrial products developed 60 years ago. Used in refrigerators, automobile air conditioners, solvents, aerosol propellants, insulation. The most powerful of the greenhouse gases, one molecule of the most dangerous CFC has about 20,000 times the heat-trapping power of a molecule of carbon dioxide. In the stratosphere, CFCs cause another problem: each CFC molecule can destroy 10,000 or more molecules of ozone.

NITROUS OXIDE (N_2O): sources include burning of coal and wood, and soil microbes' digestion. Long-lasting gas that eventually reaches the stratosphere where it helps destroy the ozone layer.

OZONE (O_3): an unstable form of oxygen. Produced by photochemical processes in the atmosphere, when nitrogen oxides react with organic compounds. In the lower atmosphere, ozone is a greenhouse gas.

Trends

- Atmospheric concentrations of greenhouse gases are rising at unprecedented rates.
- Total global energy use is projected to grow at an annual rate of 1.5-2 percent. Nonfossil energy sources are likely to become more important because of concern over global warming.
- Large-scale climate changes may occur unless other climatic systems counteract the warming effect of the greenhouse gases.
- More biologically damaging ultraviolet radiation will reach the Earth's surface if the stratospheric ozone layer degrades.

1.3 Facts About Energy Use

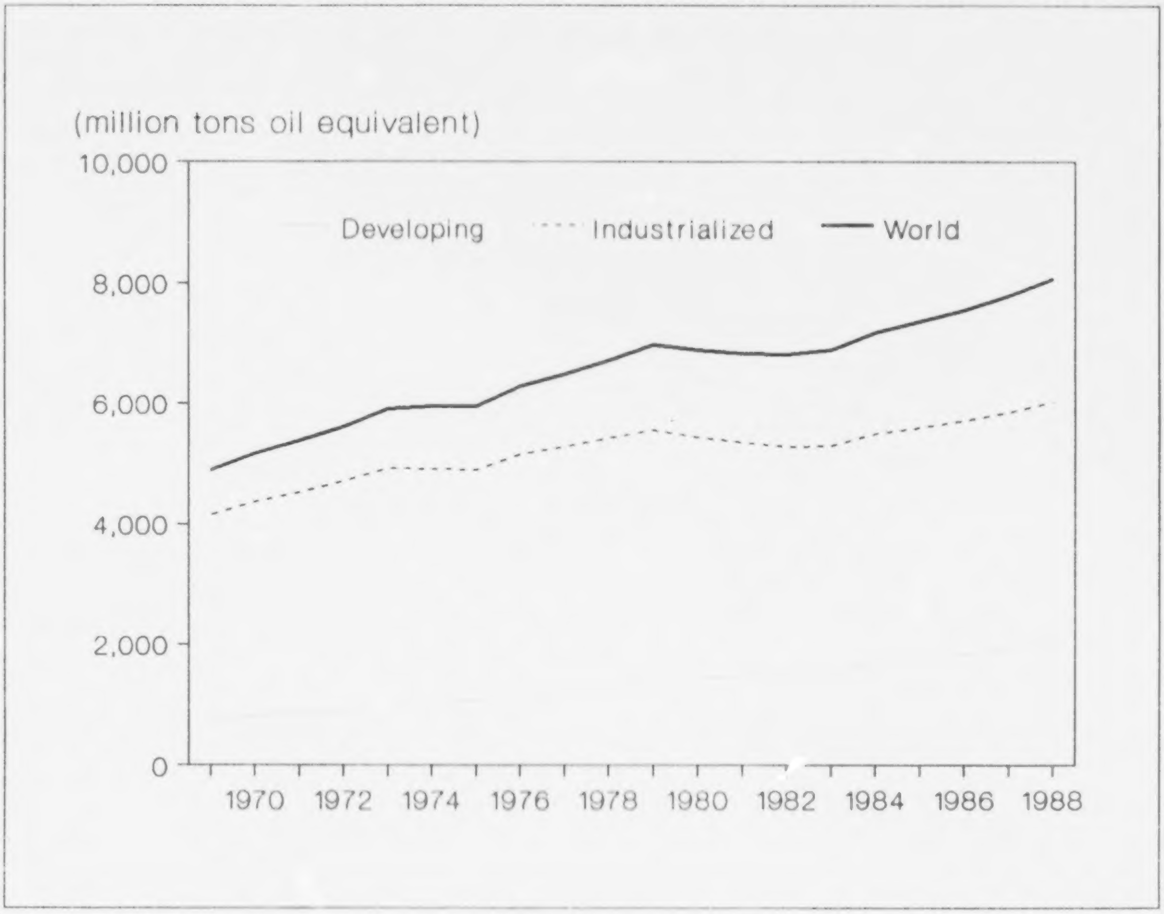
	Developed Countries	Developing Countries
	Energy consumption is increasing more slowly than in developing countries. However, per capita energy consumption is many times higher than in developing countries.	Energy consumption is increasing rapidly as industries are built up and electricity and transportation networks are built.
Oil	OECD* countries use more than half of all oil consumed.	Usage is increasing because of the rising number of motor vehicles.
Coal	Heavy users are United States, U.S.S.R., Western Europe.	Use of coal will grow rapidly. Coal now provides 3/4 of China's energy needs.
Natural Gas	Largest consumers are United States and U.S.S.R.	Use rising significantly in Southeast Asia, Latin America, and Africa.
Nuclear Power	United States and U.S.S.R. are leading producers.	Argentina, Brazil, India and Pakistan are the only countries with operating commercial reactors.
Hydro-electric	Canada and United States are biggest users, then Western Europe and U.S.S.R.	Many countries are installing small-scale hydro-electric units. Hydro-electric is an important power source in South America.
Biomass	Biomass provides only a small part of the energy consumed in developed countries--less than 5 percent in the United States.	Wood is the primary energy source for a majority of the world's people. Fuelwood supplies 80 percent of the energy needs in sub-Saharan Africa. Brazil produces ethanol from sugar cane.

* OECD countries are those belonging to the Organization for Economic Co-operation and Development (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Great Britain, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United States).

BEST COPY AVAILABLE

1.3 Facts about Energy Use

World Consumption of Energy, 1970-88



Source: British Petroleum (BP), *BP Statistical Review of World Energy*

Notes:

a. "Million tons of oil equivalent" converts the energy content of coal, natural gas, and primary electricity to their equivalent in tons of oil. This graph does not include energy from biomass (fuelwood, charcoal, etc.), solar, or wind.

b. Note that energy consumption declined in developed countries in the early 1970s and again in the early 1980s in response to oil price increases by OPEC. As prices eased in the late 1980s, consumption increased.

1.4 How Five Countries Contributed to the Greenhouse Heating Effect, 1987

Country	Carbon Dioxide (000 tons carbon)					Methane (000 tons of methane)				
	Cement Manufacture	Coal	Oil	Gas	Deforestation	Solid Waste	Livestock	Hard Coals	Wet Rice	Pipeline Leakage
United States	10,800	473,900	595,100	264,500	6,600	17,600	7,700	4,100	560	16,500
Brazil	3,900	11,000	41,900	1,700	1,322,400	350	8,300	40	540	560
China	26,400	529,000	925,600	8,000	X	2,800	4,800	4,600	19,800	X
India	5.500	121,200	38,600	3,500	154,300	2,000	11,000	920	19,800	200
U.S.S.R.	20,900	407,700	374,700	330,600	0	4,800	8,900	2,900	350	4,100

Source: World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1990-91*, (Oxford University Press, New York, 1990).
Note: Converted from metric tons and rounded to two significant digits.

1.5 Cutting Energy Use and Carbon Emissions

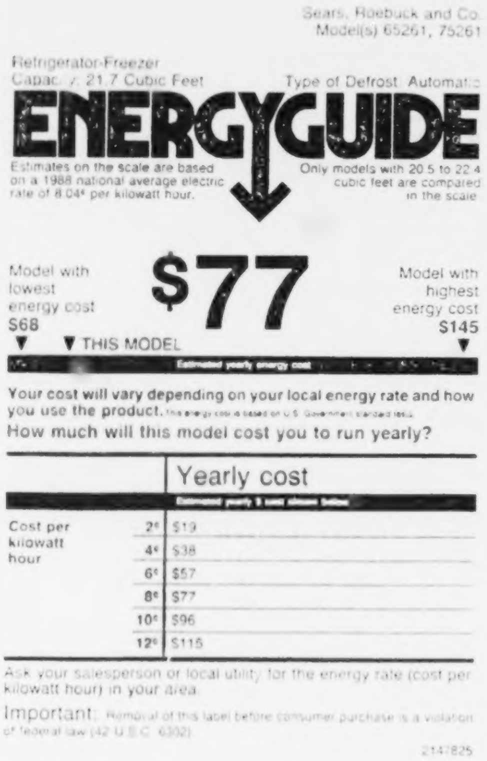
Each year carbon emissions from the United States total 1.3 billion tons, or 11,000 pounds per person. Here's how you and your family can cut your share of carbon output by saving energy. If you save 1 kilowatt-hour, that represents a savings of 0.4 pounds of carbon not released to the atmosphere.

The United States puts out 1.3 billion tons of carbon annually. With a U.S. population of 250 million, that's 5.2 tons per person per year. Granted, much of this total comes from industry, but we can each reduce our portion of carbon output by making everyday decisions to use energy in a way that produces less carbon. By rating yourself on the following chart, see how many ways you *do* or *can* use energy to slow global warming! (*General rule of thumb:* If you save 1 kilowatt-hour, that represents a savings of 0.4 pounds of carbon not released to the atmosphere.)

	Energy Savings	Reduction in Carbon Emissions
Home		
Improving insulation in your hot water heater	300 kilowatt-hours per year (kwh/yr.)	120 lb
Switching from resistance heater to heat pump	2,000 kwh/yr	800 lb
Switching from typical refrigerator/freezer to more efficient model	1,250 kwh/yr	500 lb
Updating central air conditioning	1,000 kwh/yr.	400 lb
Substituting an 18-watt compact fluorescent light for a 75-watt regular bulb (8 hours/day)	170 kwh/yr	70 lb
Car		
Carpooling instead of driving alone, for five friends	1,000 gallons gasoline/yr	5,000 lb
Taking inter-city train instead of air flight	2 gallons oil per 100 miles	10 lb. per 100 miles
Not driving (the average U.S. car goes 10,000 miles per year)	500 gallons	2,650 lb
Driving a car with 30 m.p.g. (instead of car with 20 m.p.g. for 10,000 miles)	167 gallons	880 lbs
Driving a car with 40 m.p.g.	250 gallons	1,320 lb
Driving a car with 50 m.p.g.	300 gallons	1,580 lb
Tuning up your car (at average 500 gallons/yr)	50 gallons/yr	265 lb
Community		
Using a push mower instead of power lawn mower	5 gallons gasoline/yr.	26 lb
Planting trees to the south and west of your home	500–1,500 kwh/yr	1,000 lb/yr (from both carbon stored in trees and energy saved from reduced air conditioning)

(continued)

Recycling	Cuts Pollution
Recycling glass	22%
Recycling paper	73%
Recycling aluminum	95%



Sears, Roebuck and Co.
Model(s) 65261, 75261

Refrigerator-Freezer
Capacity: 21.7 Cubic Feet

Type of Defrost: Automatic

ENERGYGUIDE

Estimates on the scale are based on a 1988 national average electric rate of 8.04¢ per kilowatt hour.

Only models with 20.5 to 22.4 cubic feet are compared in the scale.

$77

Model with lowest energy cost $68

Model with highest energy cost $145

▼ THIS MODEL

Estimated yearly energy cost

Your cost will vary depending on your local energy rate and how you use the product. This energy cost is based on U.S. Government standard tests.

How much will this model cost you to run yearly?

		Yearly cost
		Estimated yearly $ cost shown below
Cost per kilowatt hour	2¢	$19
	4¢	$38
	6¢	$57
	8¢	$77
	10¢	$96
	12¢	$115

Ask your salesperson or local utility for the energy rate (cost per kilowatt hour) in your area.

Important: Removal of this label before consumer purchase is a violation of federal law (42 U.S.C. 6302).

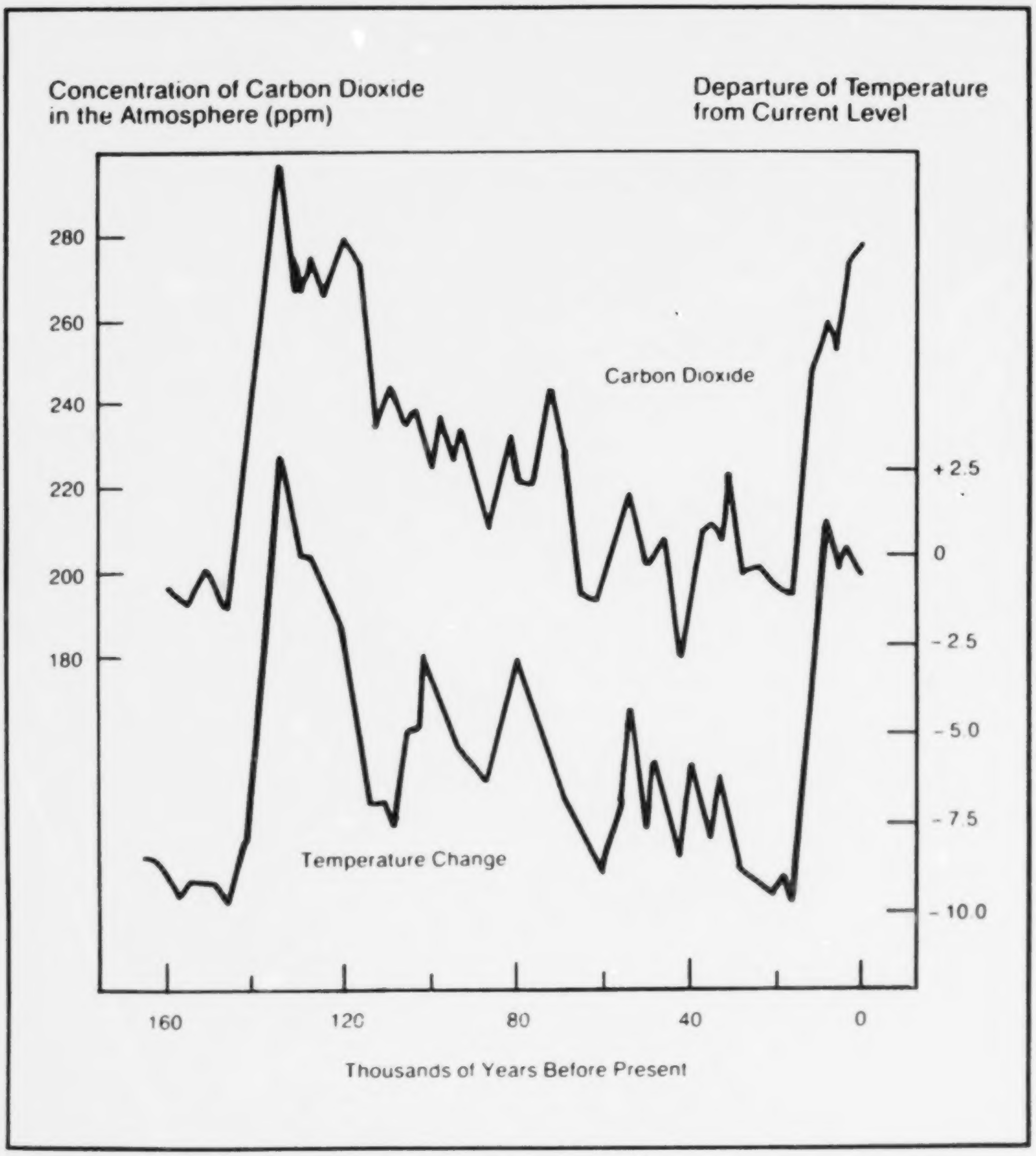
2147825

Source: Adapted from Francesca Lyman, with Irving Mintzer, Kathleen Courrier, and James MacKenzie, *The Greenhouse Trap* (Beacon Press, Boston, 1990).
Note: "Energyguide" is a sample energy use label on a U.S. refrigerator/freezer.

Overhead Master 1.3

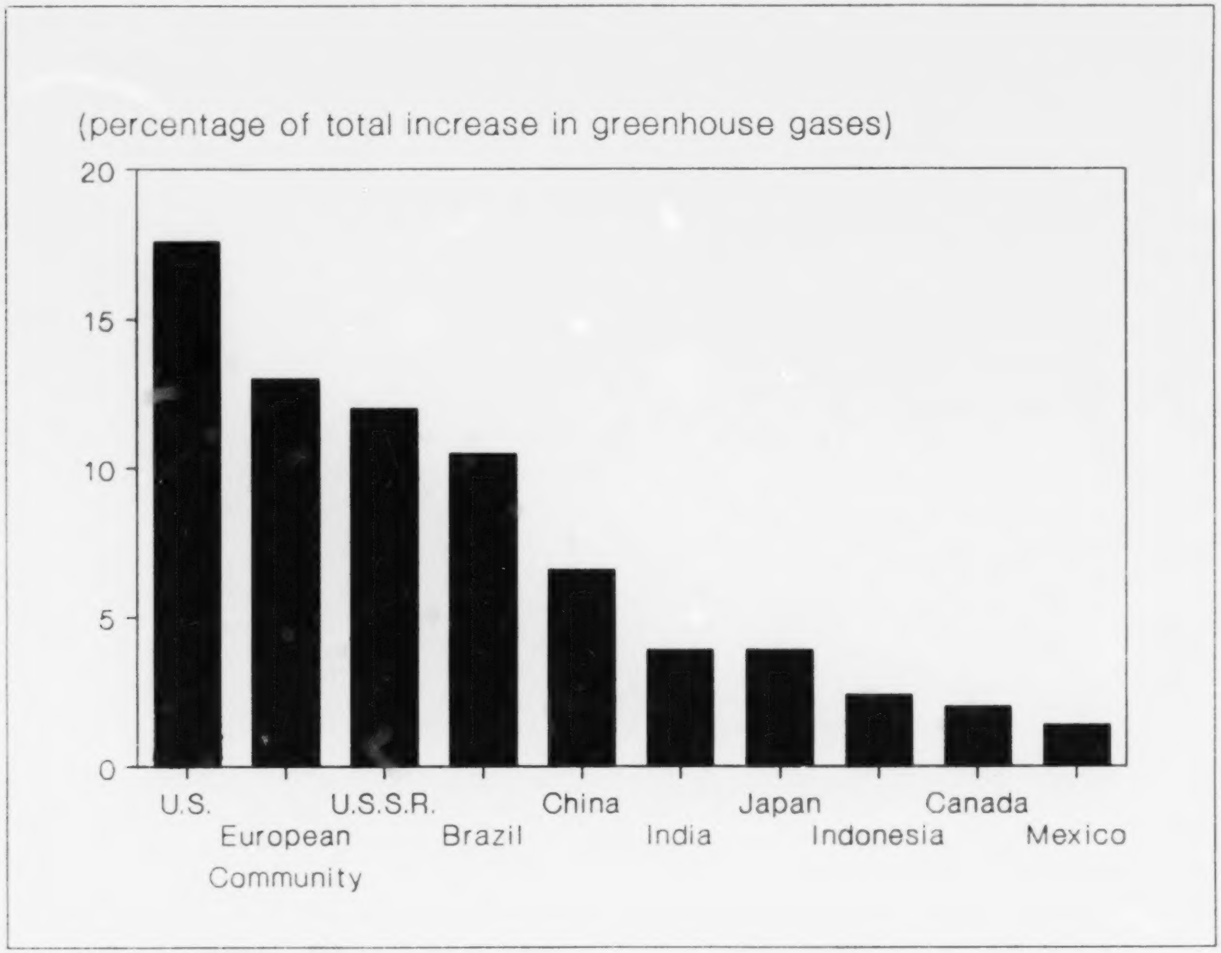
World Resources Institute

Long-Term Variations of Global Temperature and Atmospheric Carbon Dioxide



Source: J.M. Barnola, *et al.*, "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2," *Nature*, Vol. 329, No. 6138 (1987), p. 410, as cited in World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1990-91*, (Oxford University Press, New York, 1990).

Greenhouse Index: 10 Countries with the Most Greenhouse Emissions, 1987

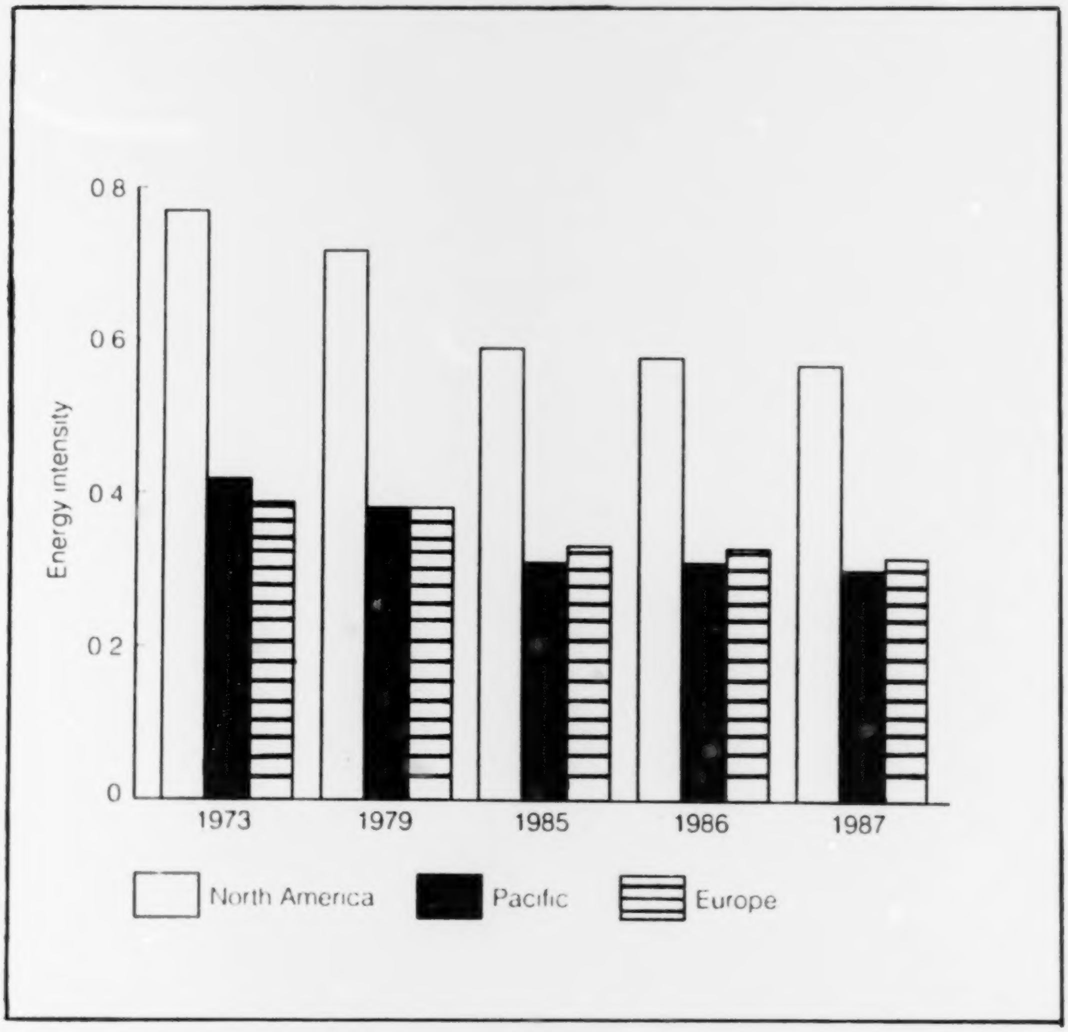


Source: World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1990-91*, (Oxford University Press, New York, 1990).

Overhead Master 1.5

World Resources Institute

Trends in Energy Intensity in Developed Countries, 1973-87



Source: United Nations Environment Programme, *Environmental Data Report* (Basil Blackwell, London, 1990), p. 408.

2.2 Facts about Deforestation and Biodiversity

Tropical forests are a unique and endangered resource. They provide habitat for millions of plant and animal species, recycle nutrients, protect soils and watersheds, and provide many products and services to people. These forests are being cleared rapidly, causing habitat destruction and extinction of species. Deforestation threatens biodiversity, a global resource made up of the variety and variability of life forms on Earth, both wild and domesticated. Biodiversity includes 1) genetic diversity, 2) species diversity, and 3) ecosystem diversity.

State of the Forests

- About one third of the world's land area is covered by forests.
- Just over one half of the world's forests are in developing countries.
- New studies indicate the world is losing 50.4 million acres (20.4 million hectares) of tropical forests each year.
- Causes of deforestation include permanent conversion to agricultural land; logging; demand for fuelwood, fodder, and other forest products; grazing, fire, and drought.
- The highest rates of deforestation are now in South America and Asia.
- Countries with high rates of tropical deforestation include Brazil, Costa Rica, India, Myanmar (formerly Burma), the Philippines, Viet Nam, Cameroon, Indonesia, and Thailand.
- Brazil has 30 percent of the world's tropical forests and the largest area of annual deforestation. The vast majority of trees cleared in the Amazon region are burned or left to rot.
- Deforestation is second only to burning of fossil fuels as a human source of carbon dioxide, one of the major greenhouse gases that may cause the global climate to warm.
- Deforestation leads to soil degradation and destroys habitat, leading to the extinction of plants, animals, birds, and insects.

State of the World's Habitat and Species

- The most important habitats for protecting global diversity are the tropical moist forests of Southeastern Asia, central and west-central Africa, and tropical Latin America. These forests contain more than half of all species.
- At least half of the world's species are contained in just 7 percent of the world's land surface.
- The exact number of species on Earth is not known. Less than 5 percent of species in the tropics have been identified.
- An estimated 100 species per day are becoming extinct.
- Only 4 percent of the world's land surface is in national protected areas. The total area protected in each country varies from a high of 38 percent in Ecuador to less than 1 percent for 55 countries.

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HUMAN MASSES, GREENHOUSE GASES

Concept: The more people there are on Earth, and the more fossil fuels they consume, the greater are the accumulations of gases that aggravate the greenhouse effect.

Objectives:

- Students calculate the amount of carbon dioxide released by automobiles in the U.S. and in the world each year and determine the amount of forest land needed to absorb these levels of carbon dioxide.
- Students calculate one family's production of carbon dioxide in a year and determine how much forest land is needed to absorb this amount of carbon dioxide.

Subject Areas: Science, Math

Materials:

Student worksheets (one per student)
Calculators (optional)
Pencils or pens and scrap paper for calculations
Graph paper, straight edge and sharp pencils of two colors

Introduction:

As more and more people come to live on the Earth and energy use continues to increase, we are putting more and more carbon dioxide, methane and other gases into the atmosphere. These gases intensify the greenhouse effect, making the Earth's climate gradually warmer and warmer.

Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has increased by more than 25 percent. In just the last 30 years, it has increased by 9 percent. Both the exponential growth in human numbers and the increasing consumption of energy per capita are contributing to this dangerous trend.

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Procedure:

Duplicate the student worksheet at the end of this activity so that there are enough for each student to have one. Then have students complete the exercises on the worksheet, working individually or in small groups. Follow up with the activity, "Global Warming Begins at Home," done as a class. Then lead a class discussion guided by the following questions:

1. What kinds of human activity contribute to the greenhouse effect?
2. Planting trees can help combat global warming, but the single best way for people to reduce their impact on the climate is to cut down on the amount of carbon dioxide they produce through the use of fossil fuels. What are some specific ways a person can reduce his or her use of fossil fuels? (Note: Many possible answers may be found in *Making a Difference*, included in this teaching kit.)

Answers to Student Worksheet Questions:

1. Walking, bicycle, public transportation systems (e.g., buses, electrically-powered trains, cable cars)
2. a) 600,000,000 tons
   b) 230,769,000 acres. This is approximately equal to the the land area of the entire National Forest System of the United States.
   c) 3,529,412,000 tons
   d) 1,357,466,000 acres
   e) 2,121,000 square miles. This is approximately equal to the combined land area of all the United States west of the Mississippi River except Alaska and Hawaii.
   f) 8,461,538,000 acres
   g) 13,221,000 square miles. This is approximately equal to the area of the Western Hemisphere minus Brazil.

Continued on following page

Activity: Global Warming Begins at Home*

1. Calculate approximately how much carbon dioxide one family's activity adds to the atmosphere in a year. (Ask for a student or parent volunteer to provide the data needed for the classroom activity from their household records. Alternatively, use data from your own household or that of someone not associated with your class.) Use the following guidelines:
    - a) Find out how many miles the family drove in the past year and how many miles per gallon of gasoline the family car gets. (If there is more than one car, get these figures for each car.) Divide the miles driven by the miles per gallon to calculate how many gallons of gasoline the family car(s) burned during the year. Each gallon burned produces 20 pounds of CO_2.
    - b) Find out from the local power company how the power plant generates the family's electricity (e.g., whether it is coal-fired, uses hydropower or nuclear energy). On utility bills, look up how many kilowatt-hours of electricity were used in the home in a year. Each kilowatt-hour of electricity generated in a coal-fired power plant produces three pounds of CO_2. (Hydropower and nuclear energy are CO_2-free.)
    - c) Look up how much natural gas was used in the home in the past year. Burning a hundred cubic feet of natural gas (1 ccf) produces 12 pounds of CO_2. (1 ccf is equal to 1 therm or 100,000 BTUs.)
    - d) Estimate how many miles family members flew on trips taken for business or pleasure in the past year. Flying one mile in an airplane generates approximately one-half pound of CO_2 per passenger.
    - e) Add the total amounts of CO_2 in a)—d) above to calculate the family's direct production of CO_2. Then double that figure to account for the CO_2 produced indirectly through the purchase of goods and services. (Carbon dioxide is used in the production of many items you buy, in the heating and cooling of public buildings you use, etc.)

2. One forest tree absorbs 13 pounds of carbon dioxide each year; one acre of trees absorbs 2.6 tons of carbon dioxide each year. How many trees would be needed to absorb all this CO_2? How many acres of trees?

Extension Activity:

Get your students involved in a tree planting project around your school or community. Such an activity might be especially appropriate around Arbor Day. The National Arbor Day Foundation at 100 Arbor Avenue, Nebraska City, NE 68410 can tell you when Arbor Day will be celebrated in your state. Contact the American Forestry Association (P.O. Box 2000, Washington, D.C. 20013) to receive further ideas on how to show students the connections between tree planting and reducing global warming. Ask for their free *Global ReLeaf* kit.

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*Adapted with permission from James R. Udall, "Domestic Calculations: Adding Up the CO_2 You Spew," *Sierra*, July/August 1989.

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HUMAN MASSES, GREENHOUSE GASES
Student Worksheet

Certain kinds of human activity generate gases that form a layer around the Earth, trapping the sun's heat so that it cannot escape back into space. The trapped heat creates a "greenhouse effect," keeping the Earth warm enough for life to exist. If too many "greenhouse gases" are put into the atmosphere, however, it may gradually get warmer and warmer. This may cause serious climate changes throughout the world, such as droughts in farm areas. Many scientists believe this global warming has already begun.

1. Carbon dioxide (CO_2) is one of the primary gases which causes the "greenhouse effect." When gasoline is burned, carbon dioxide is released into the air. Worldwide, the production and use of automobiles account for 17% of all the carbon dioxide released from fossil fuels. Which types of transportation might release less carbon dioxide per person?

2. Trees use carbon dioxide as they grow, and they produce oxygen for people to breathe. They help keep the Earth cool by cutting down on the amount of CO_2 in the air. In an industrial society where more and more fossil fuels are burned each year, producing more and more carbon dioxide, trees are vital to the health of our planet.
   a) Driving one mile releases approximately one pound of CO_2 into the air, on the average. If Americans drive a total of 1.2 trillion (1,200,000,000,000) miles each year, how many tons of CO_2 do cars release each year? (Note: There are 2,000 pounds in a ton.) ____________ tons.
   b) One forest tree absorbs 13 pounds of carbon dioxide each year; one acre of trees absorbs 2.6 tons of carbon dioxide each year. How many acres of trees would be needed to absorb all this CO_2? (Round to the nearest 1000.) ____________ acres.
   c) Only 17% of the CO_2 which is released from burning fossil fuels comes from automobiles. How much total CO_2 is released from burning fossil fuels each year? (Round to the nearest 1000.) ____________ tons.
   d) How many acres of trees would be needed to absorb all of this CO_2? (Round to the nearest 1000.) ____________ acres.

Continued on back

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e) If 640 acres = 1 square mile, how many square miles of forest would you need to absorb all the CO_2 released in the U.S.? (Round to the nearest 1000.)
__________ square miles.

f) Worldwide, annual CO_2 emissions equal about 22 billion tons (22,000,000,000). How many acres of trees would you need to absorb all this CO_2? (Round to the nearest 1000.)
__________ acres.

g) How many square miles of trees would you need? (Round to the nearest 1000.) __________ square miles.

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Publications, Washington, D.C.

Visualizing the Impacts of Deforestation

ROSANNE W. FORTNER

Global environmental change involves simultaneous or rapidly successive alterations in the hydrosphere, lithosphere, atmosphere, biosphere, and cryosphere. In fact, it is impossible to isolate any single Earth sub-system. For example, we cannot teach about sea-level rise without presenting information about coastal land use, wetlands protection, glacial melting, and the greenhouse effect.

The same situation occurs when we look at biomass burning. In the Brazilian Amazon, the extent of the burning is so great that it affects not only local, but also global, ecology. In the past, environmentalists have emphasized that everything within a local ecosystem is interrelated. Now we must realize that that interrelatedness extends throughout the global community.

Although this activity focuses solely on tropical deforestation, it is important to point out to students that temperate forests are also being destroyed faster than they can be replaced. Historically, this has led to the deforestation of many Mediterranean and Middle Eastern countries, with the consequent flooding, loss of top soil, and general degradation of the habitat. The same thing could happen in largely temperate North America. Temperate forests are also a part of the global biomass. Their destruction contributes to global changes in the atmosphere and affects the climate.

Investigating Biomass Burning

In this investigation, middle and high school students will examine the extent and impact of biomass burning and deforestation in Brazil as an example of the global problem.

Objectives

When the students have completed these activities, they will be able to

- describe the extent of the Earth's land mass that has been deforested in recent years, and
- develop a conceptual scheme that demonstrates relationships between biomass burning and other global environmental changes.

Activity 1
How Extensive is the Problem of Biomass Burning?

Teacher Background

According to estimates made by the Food and Agriculture Organization of the United Nations, during the period 1981–1990, dense tropical forests throughout the world disappeared at a rate of over 40 million acres a year. This figure represents an area the size of the state of Washington. The increased speed of deforestation is evident when you consider that this rate is 83 percent faster than the rate estimated for the period 1976–1980. Some of the tropical areas experiencing rapid deforestation are listed in table 1.

Materials

Transparencies of figures 1, 2, and 3
Photocopy enlargements of figures 4 and 5
Overhead projector

Procedure

1. Prepare transparencies of figures 1, 2, and 3. These transparencies show Brazil and the United

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ROSANNE W. FORTNER is a professor of natural resources and science education at The Ohio State University and an executive editor for *Science Activities.* Activities that she developed for this issue will also be part of a set of *Activities for the Changing Earth System,* materials produced in conjunction with the National Science Foundation project of secondary science curriculum modules for global-change education.

Table 1. Preliminary Estimates of Tropical Forest Area and Rate of Deforestation for 87 Tropical Countries, 1981–90 (area unit = 1 thousand hectares)

Regions/Subregions	Number of countries studied	Total land area	Forest area, 1980	Forest area, 1990	Area deforested annually, 1981—90	Annual rate of change, 1981—90 %
Total	87	4,815,700	1,884,100	1,714,800	16,900	−0.9
Latin America	32	1,675,700	923,000	839,900	8,300	−0.9
Central America and Mexico	7	245,300	77,000	63,500	1,400	−1.8
Caribbean Subregion	18	69,500	48,800	47,100	200	−0.4
Tropical South America	7	1,360,800	797,100	729,300	6,800	−0.8
Asia	15	896,600	310,800	274,900	3,600	−1.2
South Asia	6	445,600	70,600	66,200	400	−0.6
Continental Southeast Asia	5	192,900	83,200	69,700	1,300	−1.6
Insular Southeast Asia	4	258,100	157,000	138,900	1,800	−1.2
Africa	40	2,243,400	650,300	600,100	5,000	−0.8
West Sahelian Africa	8	528,000	41,900	38,000	400	−0.9
East Sahelian Africa	6	489,600	92,300	85,300	700	−0.8
West Africa	8	203,200	55,200	43,400	1,200	−2.1
Central Africa	7	406,400	230,100	215,400	1,500	−0.6
Tropical Southern Africa	10	557,900	217,700	206,300	1,100	−0.5
Insular Africa	1	58,200	13,200	11,700	200	−1.2

Source: Forest Resources Assessment 1990 Project, Food and Agriculture Organization of the the United Nations, "Second Interim Report on the State of Tropical Forests." (Totals may not add correctly because of rounding.)

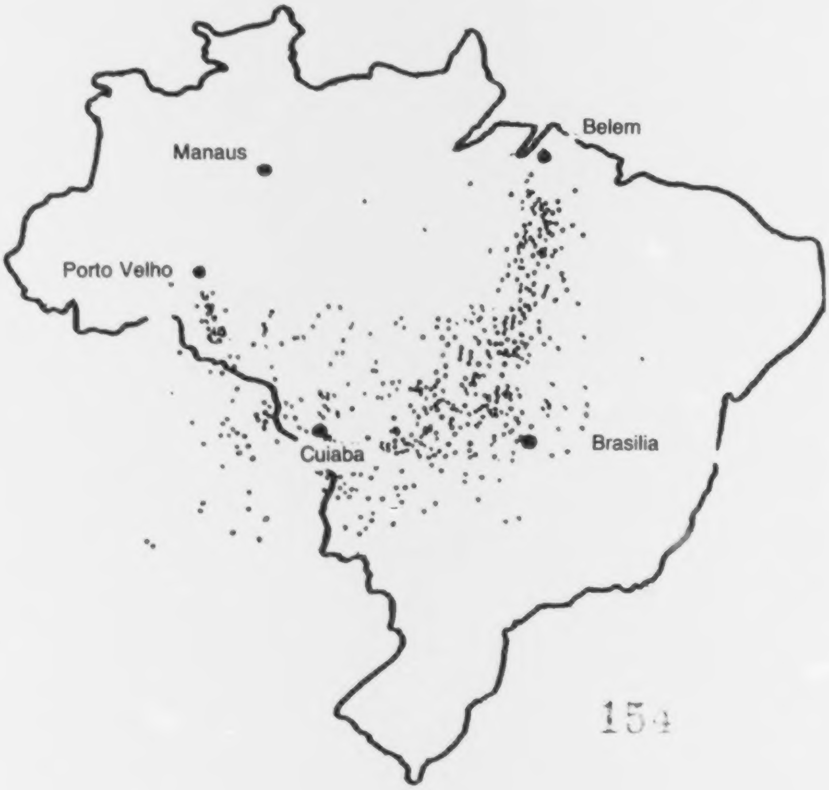

Figure 1. Map of Brazil showing areas in which forests were burning on September 1, 1987

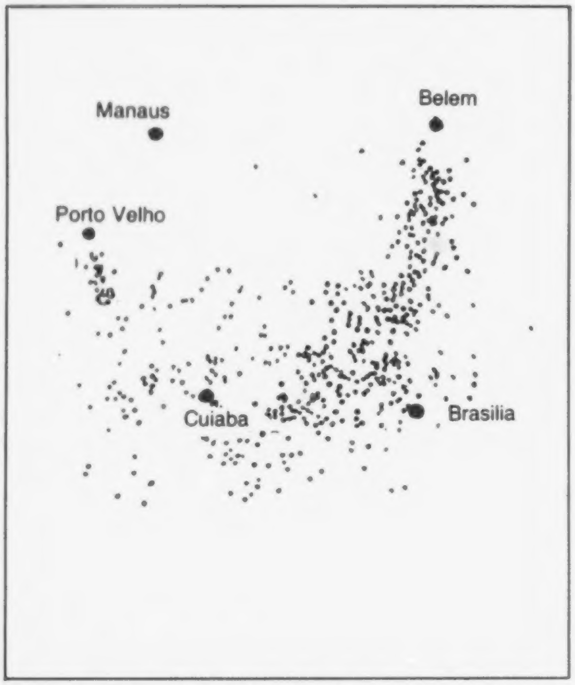

Figure 2. The points indicating forest fires abstracted from the map in figure 1

States drawn to the same scale. They will be used to compare the area of Brazil (8,511,965 km^2) to that of the coterminous United States (7,825,155 km^2) and demonstrate the large area of Brazil that is being affected by burning.

2. Display and examine the figure 1 transparency. This figure illustrates the location and number of fires that were burning in the Brazilian forests on September 1, 1987. The forests were being cleared for a number of reasons. Ask the students what they already know about what has been happening in the Amazon region. Suggest that they find newspaper and magazine articles in the library that explain why the forests were, and still are, being burned.

3. When the students have discussed the extent of the Brazilian fires, and have perhaps taken time out to do research, look carefully at figure 1 again. Tell the students that you are going to replace that map with other maps drawn to the same scale.

Then take out figure 1 and lay figure 2, which shows only the fire locations, on the projector. Overlay figure 2 with figure 3, the outline map of the United States. Rotate the dot pattern so that, as much as possible, the locations of fires fall within the outline of the United States.

The students can then count the number of states in the United States that would be affected if fires burning in the United States covered the same sized area as they do in Brazil. (This dramatic demonstration of the wide area that is being affected by biomass burning was initially presented by Richard A. Houghton of Woods Hole Research Center, Program on Global Environmental Issues, in a lecture that he gave at the American Association for the Advancement of Science in 1991.)

4. Now project figures 4 and 5. These satellite photos were taken over the same area in Brazil in 1973 and 1988. Ask the students to study the photos carefully, especially examining the cloudy material in each. List the ways in which the photos differ.

Figure 4 shows the Amazon River basin covered with normal rain clouds when the astronauts aboard Skylab 2 photographed the region in June 1973. Figure 5 shows the same area in September 1988

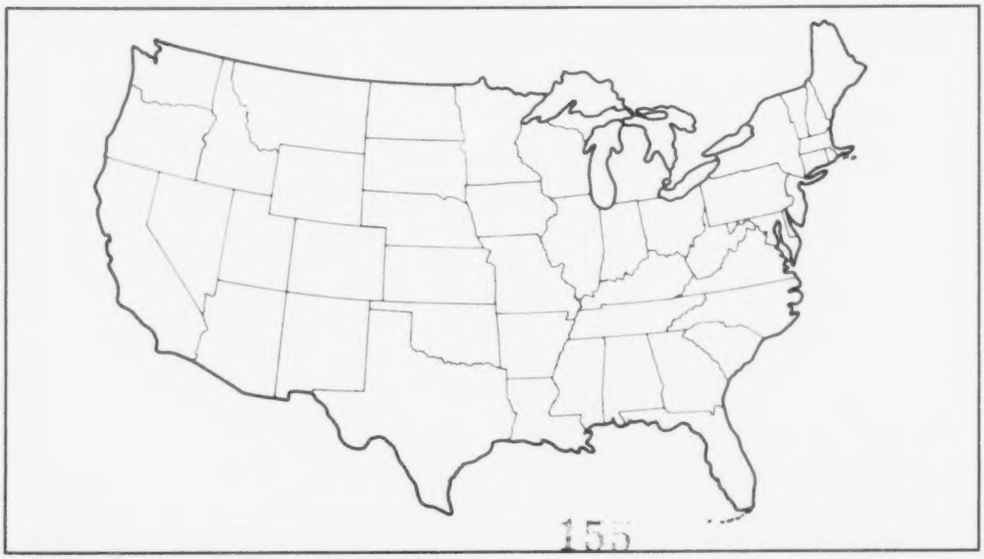

Figure 3. An outline map of the United States on the same scale as the map of Brazil in figure 1.

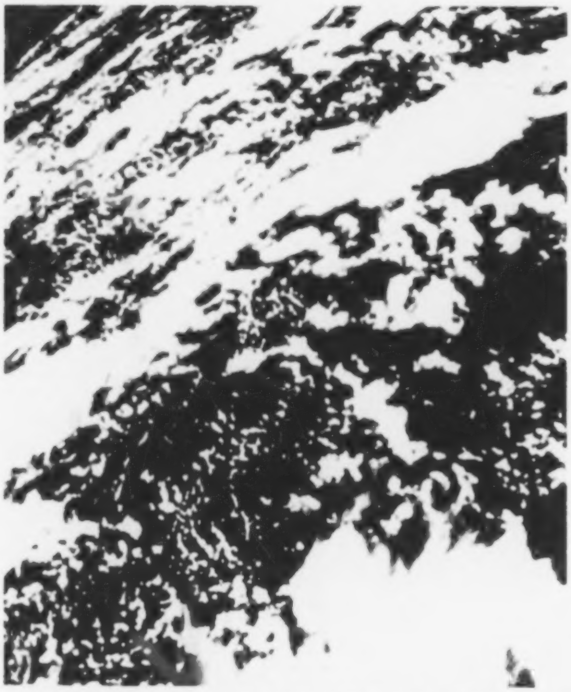

Figure 4. The Amazon river basin photographed by Skylab 2 astronauts in June 1973

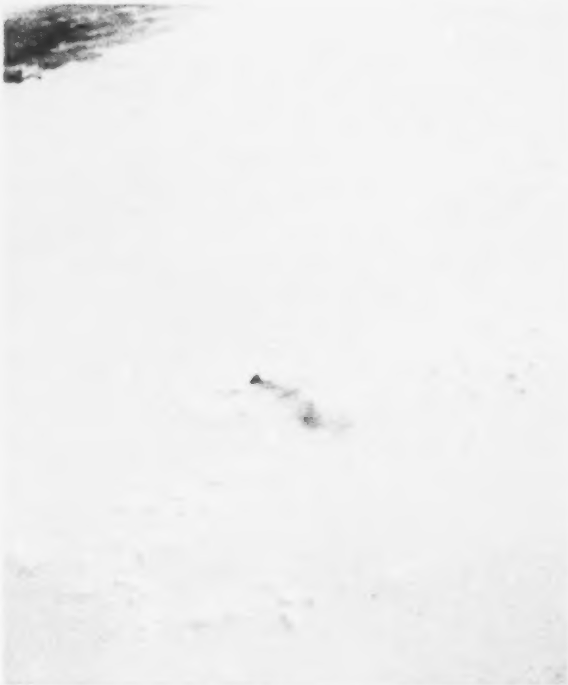

Figure 5. The area shown in figure 4, photographed from space shuttle *Discovery* in September 1988

when space shuttle *Discovery* astronauts photographed it. The cloud now covering the area is a massive smoke cloud produced by widespread biomass burning. This cloud, which measured 3,000,000 km^2, was the second largest such cloud ever recorded.

Scientists know that the white material obscuring the land in figure 5 is smoke from fires below because sensors on the satellite imaging system identified it. Discuss with the students the impact such a large amount of smoke must make on the global atmosphere. Ask the students to remember these photos and the maps that show the extent of the fires as a background for the next activity.

Activity 2

What Changes in Earth's Systems Does Biomass Burning Cause?

To help students visualize the variety and extent of impact of biomass burning and deforestation in general, use this interactive activity to develop a classroom concept map that illustrates the effects of biomass burning.

Teacher Background

The following activity is modified from one developed by Zero Population Growth, Inc. (1400 16th Street, N. W., Washington, D.C.) to demonstrate changes resulting from overpopulation. It can be adapted to study other interdisciplinary topics as well, such as global warming or disposal of toxic chemicals.

The project can be used to introduce a new topic and relate it to those previously studied or else to summarize a unit, drawing all the aspects together. Another creative approach is to take a photograph of a concept map that the students create at the beginning of the unit and compare it with a map produced after the study is finished.

Table 2. Suggested Subjects for Impact Cards

rain forest
carbon dioxide
sunlight
cows
"green medicine"
parrots
earthworms
clouds
water pollution
color
fear
endangered species
trees
air pollution
canopy
hamburgers
disease
roads
income
sunlight
erosion
global warming
peace
extinctions
oxygen
soil moisture
biodiversity
fuel wood
agriculture
native people
insects
tourism
shade
beauty
cooperation
rubber

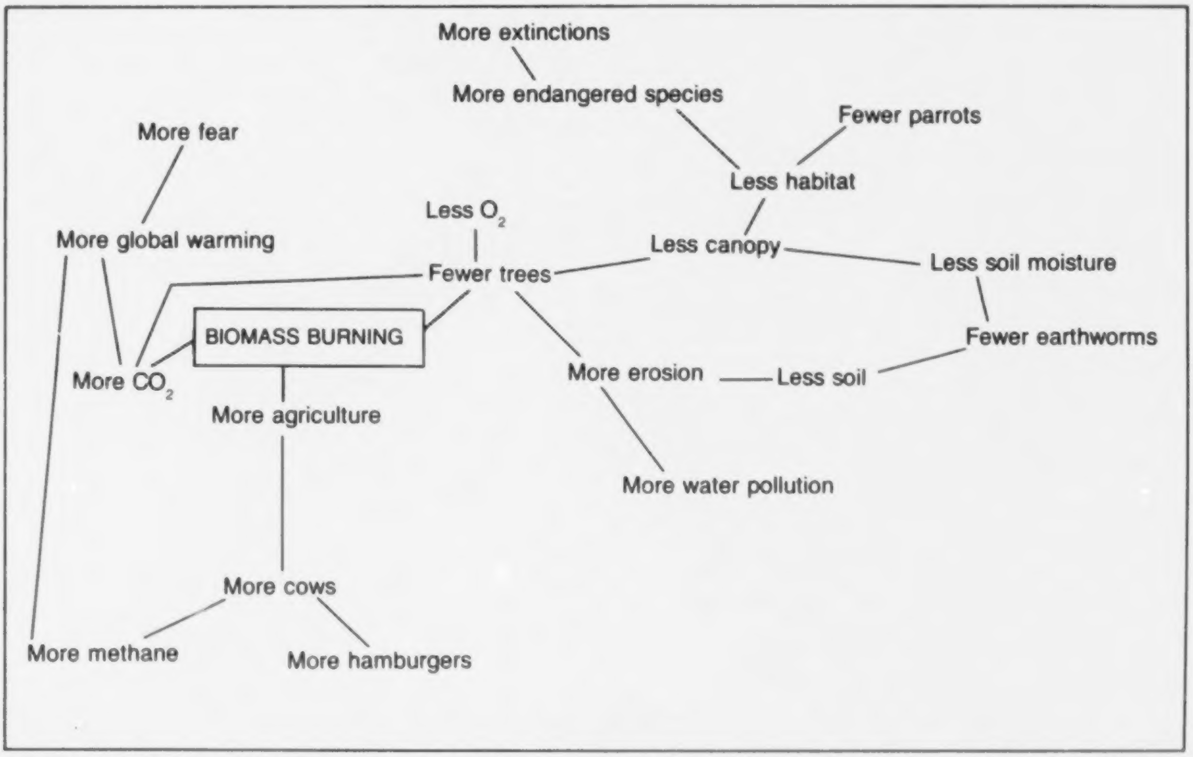
More extinctions
More endangered species
Fewer parrots
More fear
Less habitat
Less O$_2$
More global warming
Less canopy
Less soil moisture
Fewer trees
BIOMASS BURNING
Fewer earthworms
More CO$_2$
More erosion
Less soil
More agriculture
More water pollution
More cows
More methane
More hamburgers

Figure 6. A sample concept map illustrating possible impacts of biomass burning (only the part of the "Less/Fewer" card that will be read aloud is indicated)

The activity is designed for the whole class to do together during a continuing class discussion. Alternatively, it can be done in groups of four to six students. In that case, each group will create a concept map, using 3″ × 5″ cards. This approach has the advantage that students do not become impatient as they wait for turns at the board. In addition, the groups produce different maps that can be compared in a class discussion.

Materials

A large blank wall, chalkboard, or bulletin board
Tape or push pins for mounting cards
Cards made from recycled paper (suggested colors are optional):

- 1 red card labeled "Biomass Burning"
- 20 yellow cards labeled "More"
- 20 yellow cards labeled "Less/Fewer"
- 35 to 40 green impact cards that list things likely to change as a result of biomass burning or deforestation (see table 2)

Procedure

1. Choose a large area to display the concept map. Make the cards with letters large enough to be read at a distance. Think broadly in developing the impact cards. They should allow the students to demonstrate both scientific impacts and social changes. Some possible subjects for these cards are given in table 2. The class discussion during activity 1 will probably suggest many others.

2. Tape or pin the "Biomass Burning" card in the center of the wall, chalkboard, or bulletin board. Make a stack of "More" cards and a second stack of "Less/Fewer" cards. Spread the impact cards over a large table so that each card will be visible.

3. Invite the students to come forward one table or row at a time and ask them to select *either* a "More" or "Less/Fewer" card *and* a companion impact card. For example, they may decide that "Biomass Burning" leads to "More CO$_2$" or to "Fewer Trees."

They should then tape or pin these cards to whatever background you have selected and connect them with the previously mounted cards that indicate the immediate cause (see figure 6). Students must be able to justify the position of the cards they add and their choice of "More" or "Less" in describing the impact.

Discussion

As students use these cards, it will become apparent that there are various interpretations of the impacts. For instance, there are clearly more clouds, produced by smoke from biomass burning, and some students will mention that that leads to less sunlight. However, there is also no canopy, so more sunlight can reach the ground, and there could be fewer rain clouds because no moisture is being added to the atmosphere from transpiration. All interpretations should be discussed. How to weigh a variety of such correct science factors is what leads to uncertainty among decisionmakers. This is an important concept for students to understand.

Individuals or groups of students can prepare a written or oral presentation about the concept map. In their reports, they should analyze the thinking about interrelationships that produced the array and include any background material that they have gathered in research or discussion. If several concept maps are produced, each by a different small group, ask each group to report to the rest of the class.

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III

SEA-LEVEL RISE

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IUCC
INFORMATION UNIT ON CLIMATE CHANGE

Information Unit on Climate
Change, UNEP
P.O. Box 356, CH-1219
Chatelaine, Switzerland

Climate change and sea-level

▲ **The global mean sea-level may have already risen by around 15 centimetres during the past century.** According to a number of studies, the sea has been rising at the rate of 1-2 millimetres per year over the past 100 years. Measuring past and current changes in sea-level, however, is extremely difficult. There are many potential sources of error and systematic bias, such as the uneven geographic distribution of measuring sites and the effect of the land itself as it rises and subsides.

▲ **Climate change is expected to cause a further rise of about 20 centimetres by the year 2030.** Forecasts of a rising sea-level are based on climate model results, which indicate that the earth's average surface temperature may increase by 1.5-4.5°C over the next 100 years. This warming would cause the sea to rise in two ways: through thermal expansion of ocean water, and through the shrinking of ice caps and mountain glaciers. According to the Intergovernmental Panel on Climate Change (IPCC – see fact sheet 208), if no specific measures are taken to abate greenhouse gas emissions, these two factors are likely to cause the sea to rise by around 65 cm from current levels by the year 2100. This expected rate of change (an average of 6 cm per decade, with an uncertainty range of 3-10 cm) is significantly faster than that experienced over the last 100 years.

▲ **Forecasting sea-level rise involves many uncertainties.** While most scientists believe that man-made greenhouse gas emissions are changing the climate, they are less sure about the details, and particularly the speed, of this change. Global warming is the main potential impact of greenhouse gas emissions, but other aspects of the climate besides temperature may also change. For example, some studies suggest that changes in precipitation will increase snow accumulation in Antarctica, which may help to moderate the net sea-level rise. Another complication is that the sea-level would not rise by the same amount all over the globe due to the effects of the earth's rotation, local coastline variations, changes in major ocean currents, regional land subsidence and emergence, and differences in tidal patterns and sea-water density.

▲ **Higher sea-levels would threaten low-lying coastal areas and small islands.** The sea-level rise figures given by the IPCC may appear modest. However, the forecasted rise would put millions of people and millions of square kilometres of land at risk. The most vulnerable land would be unprotected, densely populated, and economically productive coastal regions of countries with poor financial and technological resources for responding to sea-level rise. Clearly, a rise in sea-level would create irreversible problems for low-lying island nations such as the Maldives and the Pacific atolls (fact sheet 203). Elsewhere, tourist beaches, cultural and historical sites, fishing centres, and other areas of special value would be at risk. The costs of protecting this land from the sea and preventing constant erosion would be enormous. Additional investments would also be needed to adapt sewage systems and other coastal infrastructure. On the other hand, some localities, such as shallow ports, would benefit from a higher sea-level.

▲ **Groundwater in some coastal regions would become more saline**. Rising seas would threaten the viability of freshwater aquifers and other sources of fresh-groundwater. Communities may have to pump out less water to prevent aquifers from being refilled with sea-water. Coastal farming would face the triple threat of inundation, freshwater shortages, and salt damage. In Indonesia, for example, agricultural settlements in marshy areas close to the coast would be highly sensitive to small shifts in ocean levels (fact sheet 104).

▲ **The flows of estuaries, coastal rivers, and low-lying irrigation systems would be affected, and tidal wetlands and mangrove forests would face erosion and increased salinity.** Wetlands not only help to control floods, but they are critical to biodiversity and to the life-cycles of many species. While many marshlands would be able to migrate inland as the sea rose, some species would suffer serious losses during the transition. Flat river deltas, which are often agriculturally productive, would also be at risk. Among the most vulnerable are the Amazon, Ganges, Indus, Mekon, Mississippi, Niger, Nile, Po, and Yangtze.

▲ **The damage caused by floods, storms, and tropical cyclones might worsen**. Major harbour areas would experience more frequent flooding during extreme high tides and, in particular, during storm surges. Countries already prone to devastating floods, such as low-lying Bangladesh, would be the most affected. Warmer water and a resulting increase in humidity over the oceans might even encourage tropical cyclones, and changing wave patterns could produce more swells and tidal waves in certain regions.

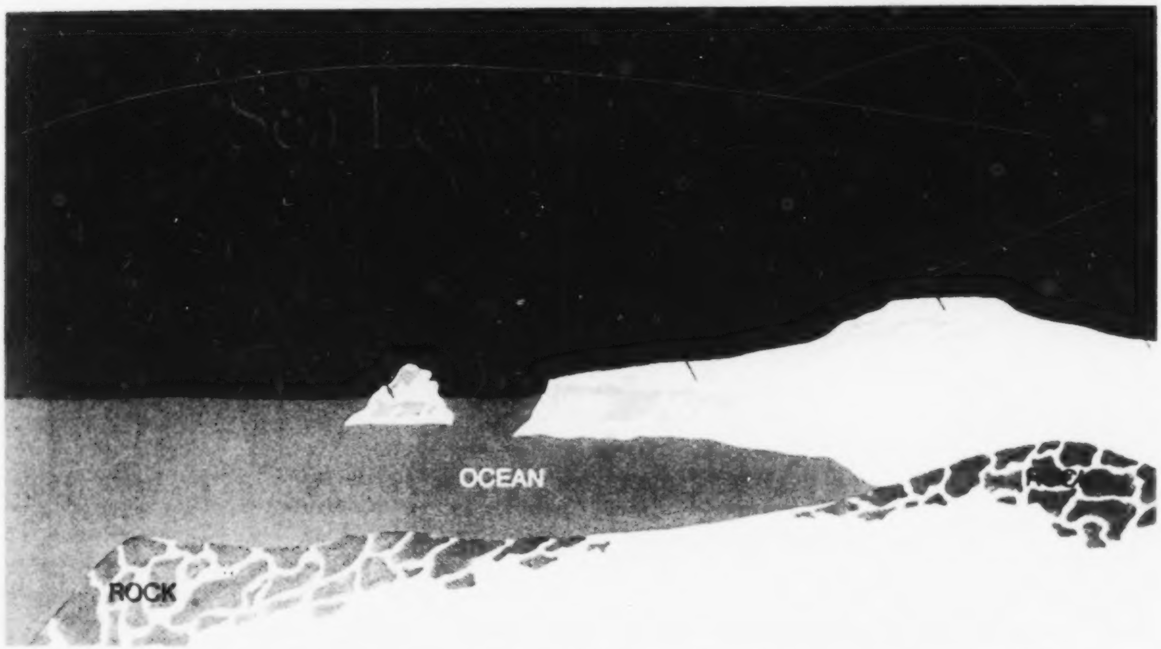
For further reading:

Jean-Claude DuPlessy and Pierre Morel, "Gros Temps Sur La Planete", Editions Odile Jacob, 1990.

Martin Ince, "The Rising Seas", London. Earthscan (1990).

Intergovernmental Panel on Climate Change, "The IPCC Scientific Assessment", Cambridge University Press, and "The IPCC Impacts Assessment", WMO/UNEP, 1990.

Reprinted with permission from *Atmospheric Carbon Dioxide and The Greenhouse Effect,* 1989, pp. 28-31 Office of Basic Energy Sciences, Department of Energy, Washington, D.C.



14. Is sea level rising?

Yes, sea level is rising, and the possibilities for future rise have probably caused more concern than any other aspect of the greenhouse effect. While some anxiety is understandable, too much alarm can distract us from knowledgeable estimates of the probabilities.

Many factors can affect sea level. The Earth's tectonic plates shift and subside, for example, and the continents are still "rebounding" from glacial pressure during the last ice age. While some of these forces tend to lower sea level, others cause it to rise.

The greenhouse effect may increase sea level because warmer temperatures could lead to partial melting of three bodies of ice that rest on land: glaciers and small ice caps around the world; the Greenland ice cap; and Antarctica. Since North Pole ice floats on ocean water, any melting there would not affect sea level--just as melting ice cubes have no effect on the level of a cold drink in a glass. Melting ice from other sources, however, would add to ocean waters, perhaps raising sea level. In addition, because water expands as it warms, a global temperature increase could also contribute to sea level rise.

Over the past century, sea level is estimated to have risen about 4 to 8 inches (10 to 20 centimeters) worldwide, according to most independent experts. Sources of the increase are less clear. About a third, scientists agree, has come from partial melting of small glaciers and other ice caps. Some has probably come from expansion of warming ocean waters. According to most specialists in ice studies, however, very little of the rise so far has come from any melting of Greenland or Antarctica.

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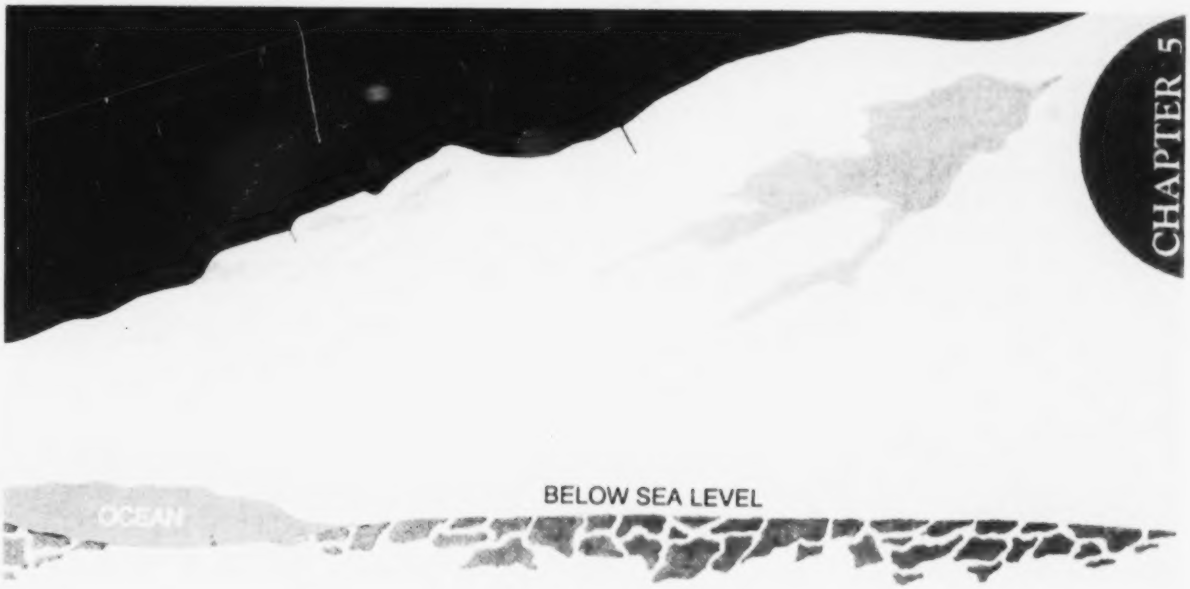

Most experts on glaciers now doubt that the huge West Antarctic Ice Sheet will disintegrate. Even if it did, they estimate that disintegration would take a century to trigger and hundreds, if not thousands of years to occur.

What about the future? Sea level will almost certainly continue to rise. The question is "how much?," and the possibilities have fueled speculation and alarm. Artists have depicted the Statue of Liberty waist-deep in water and the TransAmerica tower surrounded by San Francisco Bay. Pushing possible conditions to extremes--and thus presenting "worst case scenarios"--some research studies have even speculated that sea level would rise as much as 12 feet (3.6 meters) by the year 2100.

So what are we to believe? Because the world's ice contains most of the potential for sea level rise, scientists who study ice--glaciologists--have been asked for answers. They caution that data are very limited, especially for Antarctica, so calculations are crude. Nevertheless, they estimate that melting ice could perhaps raise sea level as much as 2 feet (0.6 meter) by 2100.

They expect some of this increase--perhaps 2 to 8 inches (5 to 20 centimeters)--to come from mountain glaciers and small ice caps and about the same amount from Greenland. More uncertain is the contribution of the Antarctic, one of the least understood regions of the planet despite 30 years of accelerated exploration.

The most dramatic question is whether the West Antarctic Ice Sheet will disintegrate, a possibility suggested several years ago by some glaciologists. This vast body of ice rests on land below sea level, buttressed by ice shelves that could melt as ocean waters warm. Scientists warning of possible collapse estimated the ice sheet might break up in as little as 200 years, producing a sea level rise of about 16 feet (5 meters).

After further study, however, most glaciologists have now discounted this possibility. They point out that a series of complicated events would have to occur, satisfying some very precise conditions, in order to produce

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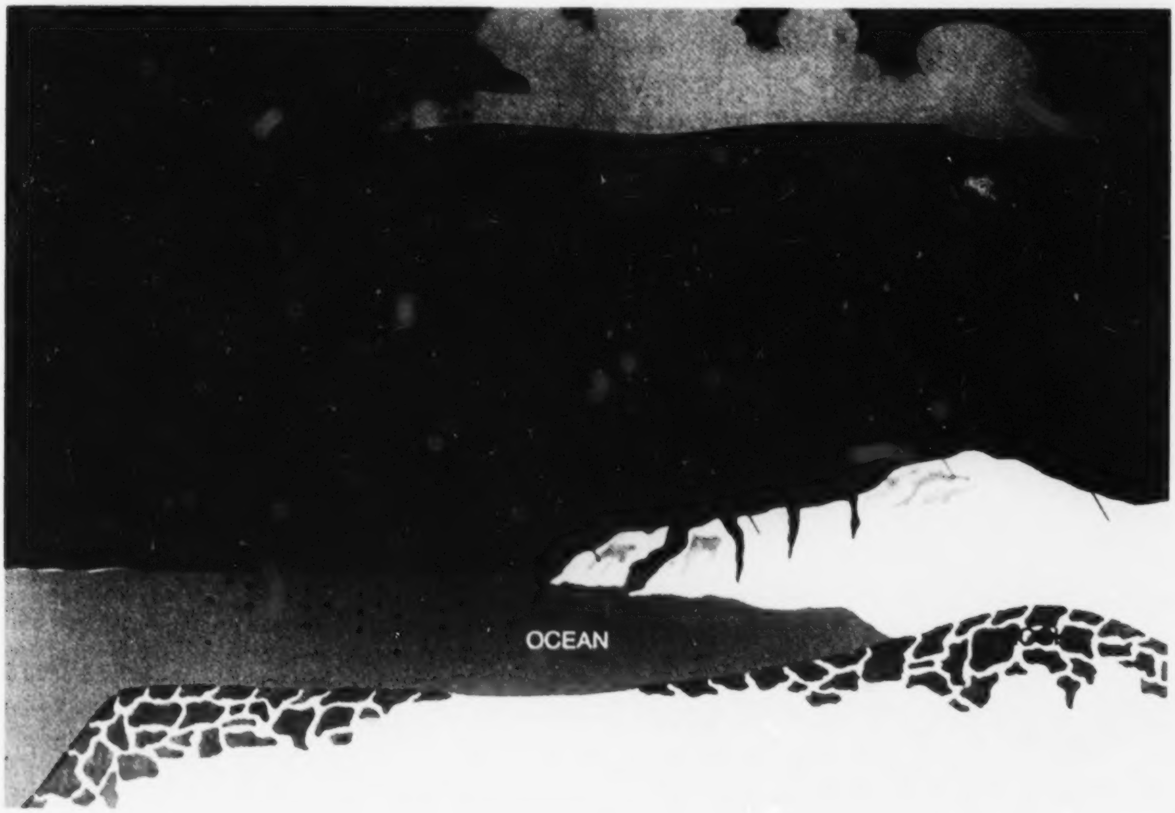

disintegration. If a breakup occurred at all, moreover, they estimate it would take a century to trigger and hundreds, if not thousands, of years for collapse to occur.

Questions remain, however, about the Antarctic's contribution to sea level. The continent has the potential to exhibit quite contrary tendencies. Ice at its edges could melt, raising sea level. At the other extreme, this surprising region could cause sea level to fall. The key factor is the extreme Antarctic cold. While air temperatures will probably warm, they are unlikely to warm enough to melt ice except at the edges. In most places, warming air will probably carry more moisture, which will then precipitate as snow. Moisture to form the new snow deposited on this enormous continent would come from the oceans and could thus lower sea level. At this point, it is uncertain which of these opposing tendencies will prevail.

In addition to melting ice, expansion of ocean waters will probably cause further sea level rise, but how much is also uncertain. In the laboratory, it is easy to show that water expands when heated, but in the oceans, complex circulation makes the effects of this simple phenomenon very difficult to assess. Data gathered from radioactive tracer studies and the World Ocean Circulation Experiment will clarify this subject. Meanwhile, one calculation often cited in scientific literature makes some assumptions about the uncertainties and estimates that ocean expansion will add 16 inches (40 centimeters) to sea levels by the year 2070.

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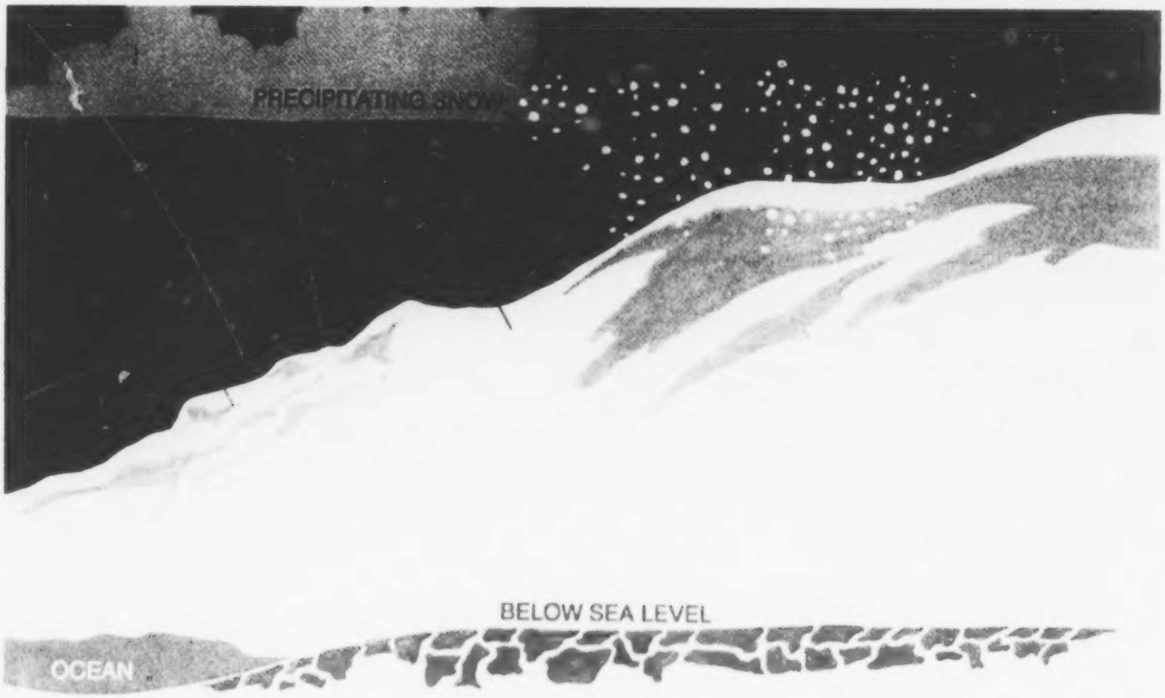
SEA-LEVEL RISE



The Antarctic might even cause sea level to fall. The greenhouse effect may warm its extreme cold, but not enough to melt most of the ice. Instead, the warmer air would absorb more moisture. The additional moisture would come from evaporating sea water, perhaps lowering sea level and blanketing this vast continent with new snow.

The uncertainties about Antarctica and about ocean waters' warming and expanding makes estimates of future sea level rise very questionable. Perhaps the best educated guess at present is that melting ice and warming ocean waters together may produce a sea level rise of about 3 feet (1 meter) by the end of the next century. The actual amount could be considerably greater or less.

Whatever the size of the increase, rising sea level may have considerable impact on coastal areas. Besides changing coastlines, for example, it may drive storm surges further inland. Residents of places like Florida and Louisiana are already experienced in dealing with such problems, and they will no doubt need all their skill to cope with these challenges.

They will also need estimates of sea-level rise based on greatly expanded knowledge of the oceans, and far-flung programs of research are underway to meet this need. Studies already mentioned will improve our understanding of ocean circulation and heat distribution. Research sponsored by the National Science Foundation (NSF) and by the Department of Energy will expand knowledge of current ice and its probable motion and alterations under changing conditions. Meanwhile, the National Oceanic and Atmospheric Administration (NOAA) is using geostationary satellites to improve the accuracy of tide gauge records. Over the next 10 years, these efforts should greatly strengthen researchers' abilities to project future sea level rise and their confidence in these estimates.

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GLOBAL CLIMATE CHANGE *and* SEA LEVEL RISE

by Douglas J. Canning

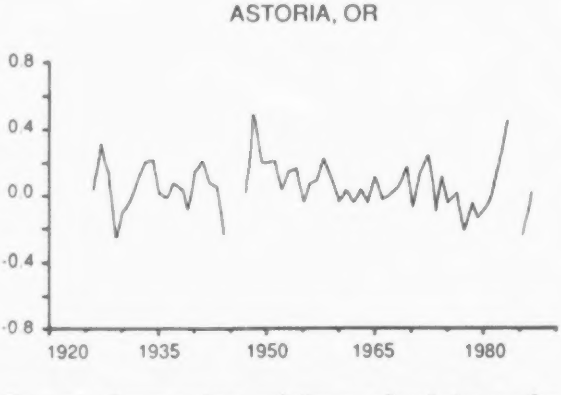
There is increasing evidence and agreement in scientific circles that the accumulation of carbon dioxide and other "greenhouse gases" will cause a global warming of 1.5 to 4.5° C within the next 50 to 100 years. While uncertainty still abounds in global climate change discussions, most scientists actually working in the field no longer debate over the direction of change, but simply over the rate and timing of global warming.

Sea Level Rise

Sea level rise is considered by many to be one of the most likely of the secondary effects of global warming. A study committee of the National Research Council concluded that "the risk of accelerated sea level rise is sufficiently established to warrant consideration in the planning and design of coastal facilities." Sea level rise—or rather accelerated sea level rise—will be caused by two factors. First, as the oceans absorb heat from the atmosphere they will expand. Second, as snow fields and glaciers melt, the amount of water in the oceans will increase.

Fourteen thousand years ago, when the present interglacial warming began, the seas were 75 to 100 meters below present levels. As the great glaciers melted, sea level rose rapidly at rates of as much as 1 meter per century. Six to seven thousand years ago the rate of rise declined to about the present rate—10 to 15 centimeters a century. Our present day coastal morphology has been shaped by the sea level rise of the recent past.

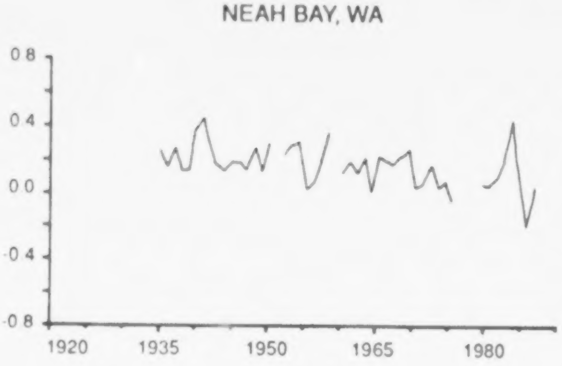
It's difficult to measure contemporary sea level rise with great accuracy because of vertical land movements. In the Pacific Northwest, for example, portions of the Pacific Ocean coast are undergoing uplift. As the Juan de Fuca plate subducts under the larger North American plate approximately 240 kilometers offshore, the leading edge of the North American plate slowly rises. Conversely, and in reaction, most of the Puget Sound inland marine area is subsiding. The tide gauges at Astoria, Oregon and Neah Bay, Washington on the ocean coast show a long-term decline in relative sea level—the land is rising faster than is the sea. The relative sea level change at Astoria is about -6 centimeters per century, and at Neah Bay about -11 centimeters per century. The tide gauge at Friday Harbor in north Puget Sound shows a long-term average change about equal to sea level rise (+12 centimeters a century), indicating a geologically stable locale. At Seattle, in central Puget Sound, the tide gauge record shows a long term sea level rise at a rate of about 20 centimeters a century between 1895 and 1986, indicating a subsidence of about 8 centimeters a century.



By way of comparison, relative sea level rise on the Atlantic coast ranges from 9 centimeters a century at Boston to 36 centimeters per century at Hampton Roads, Virginia. In Louisiana, where the Mississippi

Delta is rapidly subsiding, relative sea level rise is already on the order of 95 to 98 centimeters a century.

The National Oceanic and Atmospheric Administration has begun the planning necessary to develop an enhanced ability to measure sea level through satellite-based remote sensing. While a satellite system could be functional within a matter of years, it would be decades before a useful data base of more accurate information could be accumulated.



Although accelerated sea level rise is considered to be one of the more likely effects of global warming, there's still no great certainty as to the rate or total amount of rise. The US Environmental Protection Agency developed computer model projections of sea level rise in the early 1980s. Depending on which assumptions are made about global warming processes and global society's reactions, sea level was projected to rise between 0.6 and 3.5 meters by 2100, with a 1.4 meter scenario considered most likely. In recent years a better understanding of the processes involved has led to more-or-less of a consensus that a rise of 0.5 to 1.5 meters by 2100 is more likely. Total sea level rise has not been modeled.

A few years ago it was not uncommon to hear of 6-meter or even 60-meter sea level rise scenarios. While theoretically possible, sea level rise of this magnitude is not imminent and not likely.

The 6-meter scenario is predicated on the collapse of the West Antarctic ice shelf. This has happened in the past, possibly as recently as 160,00 years ago. The West Antarctic ice shelf is not floating on the ocean surface—it is supported by offshore ridges. Thus, a warming ocean could weaken the ice shelf causing it to fall into the ocean raising water levels. An event of this magnitude would allow the land glaciers on the Antarctic continent to move towards the oceans more rapidly, further raising water levels. Scientists who work on this issue generally agree there is a low probability of any of this occurring, and that if it did happen, it would take centuries to complete the process.

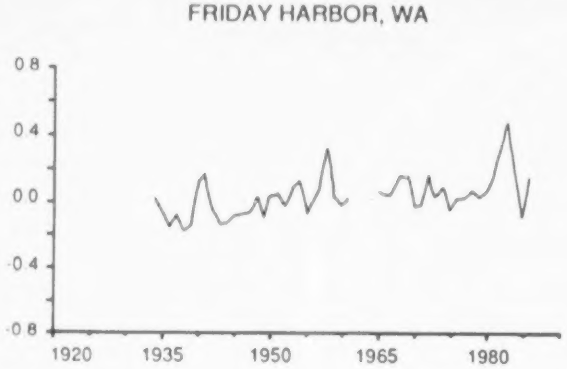
The 60-meter sea level rise scenario was based on a complete melting of the Greenland and Antarctic ice caps. This has not occurred for probably two million years. In the unlikely event that global warming becomes this severe, it would take a few thousand years for sea level rise of this magnitude to run its course.

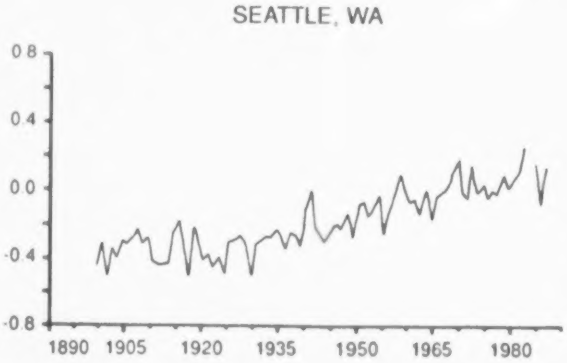
Whichever scenario plays out, it appears that at worst we can anticipate an accelerated sea level rise rate of no more than maybe a meter-and-a-half per century, and probably much less.

What are Some of the Effects?

Regardless of whether sea level rise acceleration occurs or not, the existing rate of sea level rise is already contributing to problems is some areas. Wetlands loss in Louisiana is already on the order of many square miles a year. Chronic shoreline erosion is common along most U.S. coastlines.

Among the first effects of accelerated sea level rise will be changes in shoreline accretion and erosion patterns, most noticeably increased erosion. There will also be an increase in the frequency and intensity of coastal flooding. Over longer periods of time, coastal facilities and land uses will be at risk from not just greater flooding but from inundation. In time, as sea level rise forces a rise in near-coastal water tables, soil saturation will affect the character of soils and their ability to

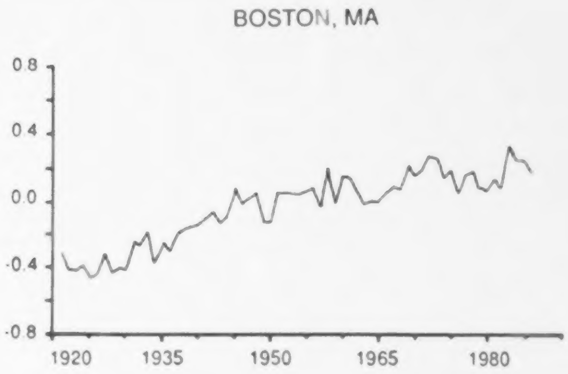


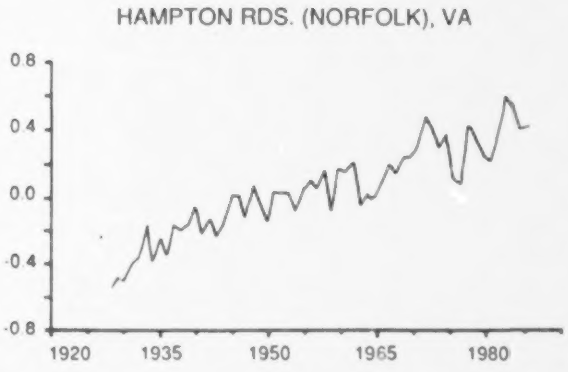


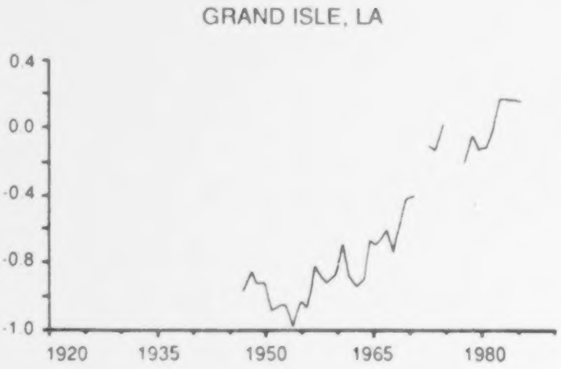
support agriculture. High water tables may also lead to corrosion of underground structures such as storage tanks and sewer and water pipes. Sea water intrusion of coastal aquifers and the resulting chloride contamination of water supplies is already a problem in heavily developed areas; sea level rise will simply aggravate sea water intrusion. Coastal biology and ecology will be affected, most noticeably through effects on wetlands.

Erosion It is quite certain that the adjustment of coastal beaches to higher sea levels will result in substantial erosion. The shorelines most susceptible to erosion are sandy beaches. Although erosion rates are difficult to predict, applications of the "Bruun rule" and similar analytical procedures suggest that a 1 foot rise in sea level would erode the shore 50-100 feet in New Jersey and in Maryland; 100-200 feet in South Carolina; 200-400 feet in southern California; and 100-1,000 feet in Florida. Technically, it is feasible to protect beaches against this kind of erosion and retreat through beach nourishment.

A study by the Delft Hydraulics Laboratory of the Netherlands is illustrative. Consider a 1 meter sea level rise. The beach nourishment necessary to stabilize our East Coast beaches will be on the order of 1,000 to 10,000 cubic meters per lineal meter. The U.S. Atlantic and Gulf coast totals about 5,000 kilometers. With the cost of a cubic meter of sand, taken either from the land or from deep water, on the order of $\$2/m^3$, the total cost to protect our Atlantic and Gulf coasts is 10 to 100 billion dollars—plus annual maintenance. It is unlikely, however, that such a solution will be politically or financially popular.







Flooding Coastal storm flooding will be affected by sea level rise as well as by climate change. Sea level rise will provide a higher platform from which storm surges may sweep inland. A more unstable climate may produce more frequent storms. Warmer oceans will result in more frequent formation of large storm systems (tropical depressions, cyclones, hurricanes); the intensity of these storm systems may also be greater. The heat and moisture from warm ocean waters are the driving force of large storm events. Thus, warming seas will impact existing and future coastal development in two ways: more frequent, and possibly more intense storm events; and, greater storm surges due to rising sea levels. This effect has been predicted for the Atlantic and Gulf coasts which are already affected by hurricanes. The situation on the Pacific coast is less certain.

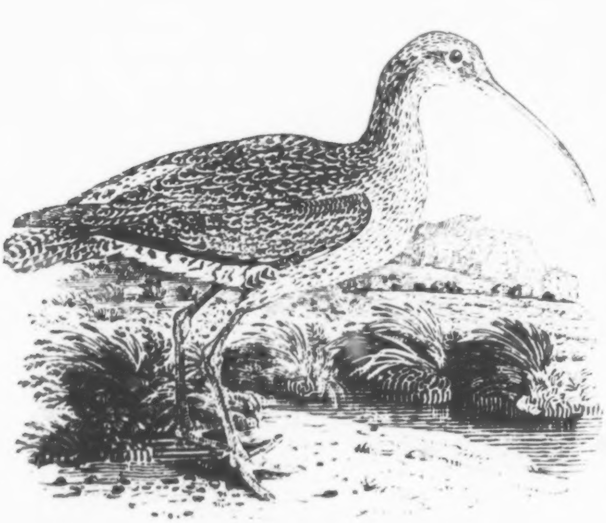
The effect of sea level rise alone is substantial. In San Francisco Bay, for example, a sea level rise of only 15 centimeters would change the frequency of the 100-year storm to a 10-year storm. In other words, the coastal storm flood which now has only a 1% probability of occurring each year, would have a 10% probability of occurring each year.

Wetlands Coastal wetlands will be particularly vulnerable to inundation and erosion. The U.S. Environmental Protection Agency has undertaken a number of studies of the effects of sea level rise upon coastal wetlands. Preliminary studies indicate that a one-meter rise would drown 25 to 80% of the US coastal wetlands. Their ability to survive would depend on whether they would be permitted to migrate inland, or whether levees and bulkheads would block their path.

SEA-LEVEL RISE

A substantial body of thought has been devoted to sea level rise and coastal wetlands at the national level; much of this research has been compiled in a U.S. EPA document, *Greenhouse Effect, Sea Level Rise, and Coastal Wetlands*. There are three principal pathways whereby sea level rise can alter coastal wetlands: inundation; erosion; and saltwater intrusion. Inundation can "drown" existing wetlands, or can create new wetlands of existing uplands or transition zones. The potential loss of wetlands to sea level rise-induced inundation and erosion will depend on the maximum rate at which wetlands can migrate inland, relative to the rate of sea level rise which is controlled by: (1) the amount of sedimentation occurring in the wetland; (2) the coastal slope (topography) inland of wetlands; and (3) whether coastal developments obstruct the migration of wetlands. Saltwater intrusion will act to convert coastal freshwater wetlands to salt marshes.

The vertical range of salt marshes is normally from about the mid-tide level to about ordinary high water (OHW). Coastal wetlands inundated by salt water once or twice a day support "low marsh" plants; areas inundated less frequently support "high marsh" species. Above the high marsh is a transition zone to upland vegetation. The transition zone may be a freshwater wetland.



Everything else being equal, the effect of sea level rise upon coastal wetlands is to force a migration of the wetland inland. If the topographic gradient landward of the wetland is constant—that is, of the same topographic gradient as the wetland—then the wetland would simply shift landward with no loss of area or change in character. Topographic gradients along the coast are not ordinarily constant. Landward of coastal wetlands the topographic gradient ordinarily increases. Therefore, as sea level rises and the wetland migrates landward, the horizontal extent of the topographic zone between the mid-tide level and ordinary high water narrows, and the extent or area of the wetland will decrease.

Where uplands landward of coastal wetlands are protected from inundation, wetlands migration will be prevented, and there will be an even greater loss of wetlands habitats.

Biology and Ecology The effects of sea level rise upon biological systems will be so entwined with climate change effects that it's difficult to attempt to separate the two. Clearly, any substantial loss of wetlands habitat will result in reductions of the populations of species dependent upon wetlands. And just as warmer temperatures will force terrestrial species to "migrate" north, so too will warmer waters cause a northward shift in the range of marine species.

Less obvious are the intertidal habitat shifts likely to occur as a result of shoreline protection to minimize erosion. In urbanized coastal areas, a likely reaction to sea level rise will be the construction of bulkheads, sea walls, and other forms of "hard" shore protection. The net result will be to fix the shoreline in place, and as sea level rises, to progressively diminish and locally eliminate the intertidal habitat, affecting the species dependent on the intertidal for some or all of their life cycle.

For example, some species of smelt (*Hypomesus* spp.) and herring (*Clupea* spp.) spawn between the upper intertidal and the upper subtidal. Anadromous species often depend upon the intertidal and subtidal shallows for a portion of their life cycle. Juveniles which use estuaries during migration or rearing phases escape predation by larger species by remaining in shallow-water habitats as much as possible.

Losses of intertidal and shallow subtidal habitats should be anticipated due to potential sea level rise response strategies for protection of shoreline properties and structures. To the extent that "hard" protection is practiced—bulkheading and riprapping—intertidal habitat will be diminished and eliminated, and shallow subtidal habitat will be made deeper. Bulkheading will fix the shoreline in place, and as sea level rises the intertidal area will become progressively smaller and may eventually be eliminated. Thus, there is great potential for the loss of intertidal spawning, rearing, and migratory habitat in highly developed areas.

Government Reaction

Most coastal states recognize sea level rise as an important issue and have existing coastal zone management policies which could be adapted to coping with sea level rise. A few states and regional governments have already adopted new management policies to address sea level rise. In 1988, Maine's Coastal Wetlands and Sand Dune Law was changed to encourage a landward retreat from a rising sea. The San Francisco Bay Conservation and Development Commission adopted changes to their Bay Plan in 1989 requiring that new development be engineered and constructed for existing sea level rise, and that conceptual planning consider accelerated sea level rise. South Carolina's coastal zone program was amended in 1988 through the adoption of the Beach Management Act which requires construction setbacks based on recent erosion rates. Washington state began its technical and policy studies in 1988.

Global Climate Change and Education

One of the more difficult aspects of addressing greenhouse effect and global climate change, whether it's developing educational curricula or making public policy, is the matter of uncertainty. In fact, we are able to absorb a great measure of uncertainty about natural systems into our educational and political policy making systems. We have learned to deal with "unforeseeable" phenomena such as earthquakes, floods, droughts, and hurricanes. It may very well be that we are less bothered by the uncertainty surrounding global climate change, than we are with having one more problem to deal with. Regardless, there is an important role for educators to play, both within the school systems and in the context of adult education.

A workshop on global climate change for educators was held in Seattle in January, 1991. The workshop was co-sponsored by Washington Sea Grant, based at the University of Washington, and King County Washington Cooperative Extension, a service of Washington State University. Many government agencies cooperated in developing the workshop, including the U.S. Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the Washington Department of Ecology. The first workshop of its kind—as far as we know—it attracted the attention of educators in other regions even during the planning phase.

The workshop was designed for a broad range of educators—secondary school teachers, community college instructors, cooperative extension and Sea Grant staff, government agency public information officers, and volunteer organization outreach staff.

The two-day conference focused on basic issues during the first day—the scientific evidence for global climate change, and basic effects on the Pacific Northwest such as energy supply and demand, forestry, agriculture, biodiversity, human health, marine fisheries, and socio-economics. The second day was devoted to two series of concurrent sessions. The first set gave participants the opportunity to learn more about specific issues—natural systems such as wildlife; managed systems such as agriculture and forests; marine and coastal issues; or socioeconomic issues. The second set of sessions was designed let the conference organizers learn what the different groups of educators need to do their job. For additional information about the conference, contact Michael Spranger, Washington Sea Grant, University of Washington, Seattle, WA 98195 (206) 543-6600.

■

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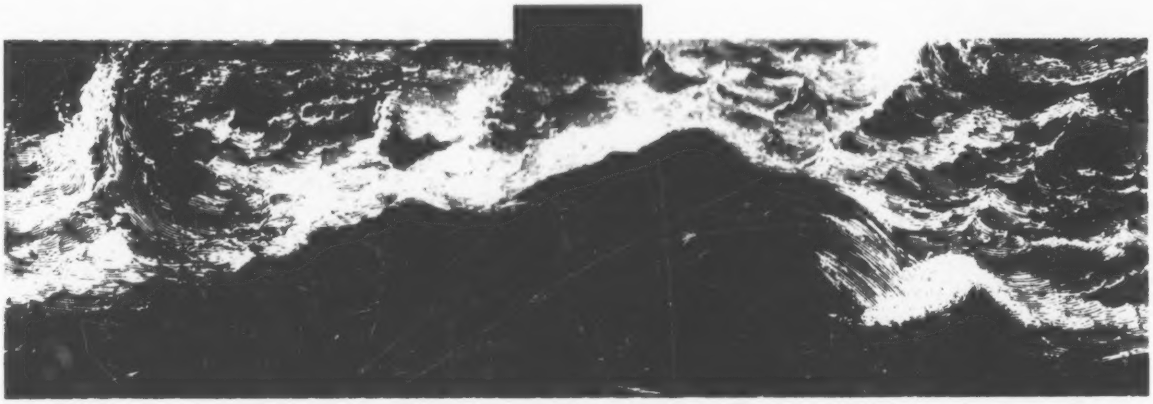

Answers to SEAQUIZ from page 33.

1. lw 2. gs 3. dz 4. hy 5. iq 6. br 7. cp 8. kx 9. au 10. jv 11. fo 12. et

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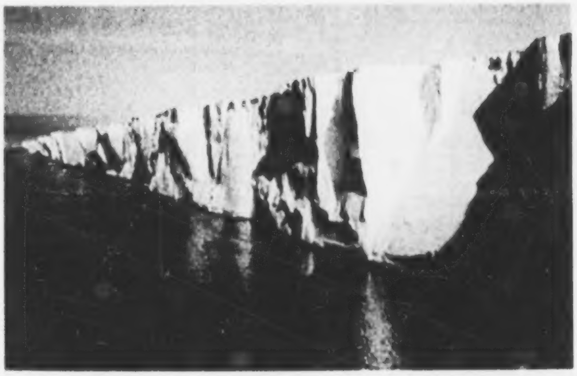
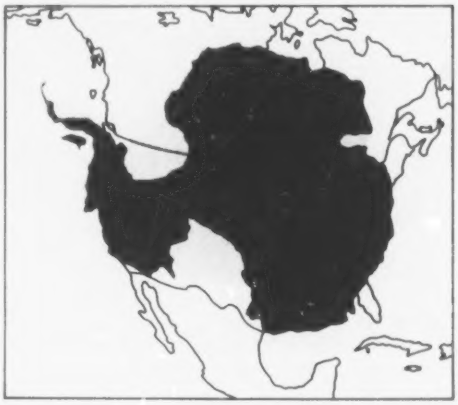
The Polar Ice Sheets: A Wild Card in The Deck?



Above, the edge of the Ross Ice Shelf, standing 25 to 30 meters above the sea surface. The dye mark on the ice sheet provides a temporary navigational reference point for repeated oceanographic observations.

by Stanley S. Jacobs

"It's getting hotter—or so most scientists predict—and you won't be able to go to the beach to cool off, because as the Earth warms, polar ice will melt and the surface of the ocean will expand, causing a sea-level rise of some 4.5 feet by the year 2030." That quote, from today's stack of mail, is typical of statements that we frequently encounter in the news media. A projected sea-level rise of 1 foot every 10 years can galvanize the attention of even a mountain dweller, but it is not a very likely scenario. Could the polar ice sheets really generate such a modern flood, given that they survived the last major deglaciation* largely intact, and have experienced only minor changes over the last several millenia? Probably not, but they should bear some close attention.



The Antarctic ice sheet is larger in area than the United States. The lightly shaded areas are the floating ice shelves.

Recent Sea-Level Rise

Careful studies of regionally variable sea level records taken over the last century indicate a global rise of about a half inch per decade. The 5-inch (12-centimeter) global sea-level rise since the late 1800s is not tied to any melting of the ice caps, but can be explained by thermal expansion of the ocean and the retreat of temperate mountain glaciers (Figure 1, page 52). The polar ice sheets thus do not appear to be the perpetrators of recent sea-level rise. This agrees with glaciological data, which suggest that Antarctica is slightly on the positive side of mass

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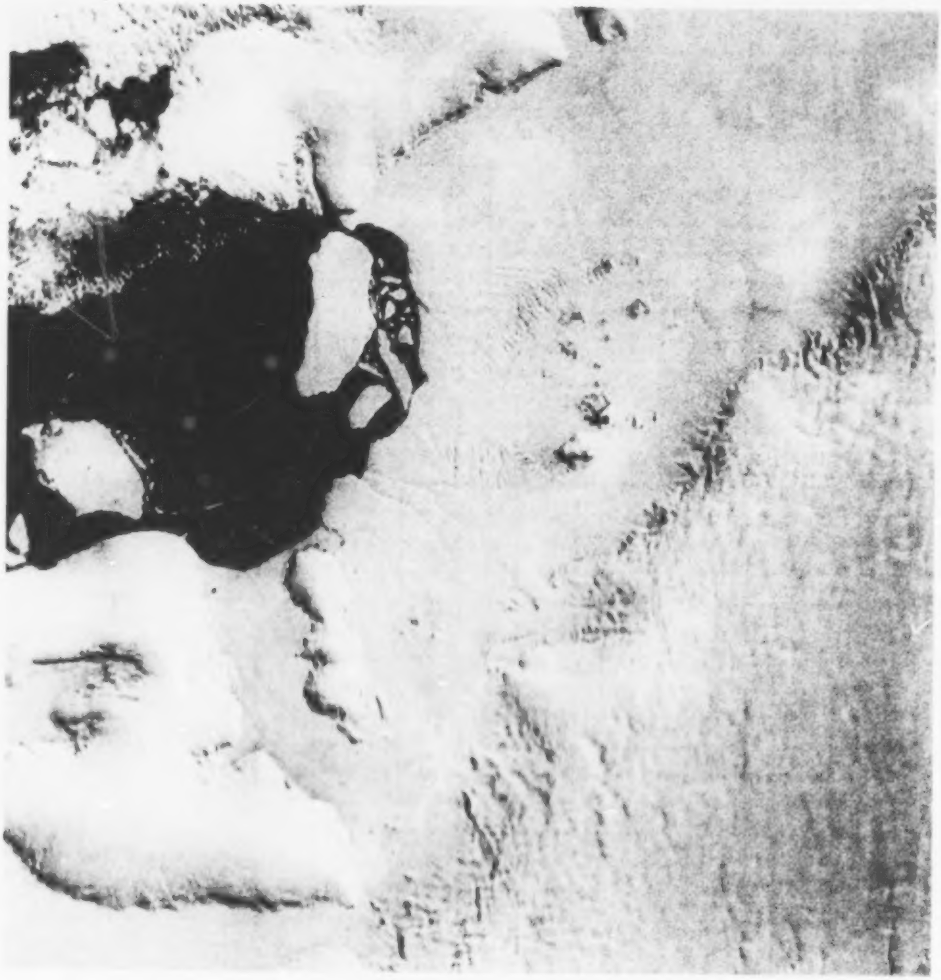
* The last deglaciation began about 18,000 years ago, removed most of the ice on the northern continents, and was essentially completed 8,000 years ago.



An example of icebergs calving from a West Antarctic ice shelf. The largest iceberg is 32 kilometers in length. This enhanced Landsat image was taken several years ago, and shows rises, crevassed areas, and flow features. Periodic imaging of the same area would reveal changes in any of these features. (Courtesy of B. Lucchitta, U.S. Geological Survey)

balance. In other words, the precipitation being added to Antarctica is slightly more than the water and ice being lost—on a time scale of years or decades. In addition, analysis of crustal rebound and wander of the Earth's pole of rotation does not reveal a mass transfer away from the polar regions, as might be expected if the ice sheets were melting.

Atmospheric Warming

Global climate models project that atmospheric warming, as a result of increasing carbon dioxide and other "greenhouse" gases, will be greatest in the polar regions. The amount of warming, estimated to be several degrees Celsius (unless balanced by feedbacks not incorporated in the models), could reduce the area and thickness of sea ice. This would not directly influence sea level, but the now permanent Arctic pack ice might not reform if removed, as surface albedo (reflectivity) would decrease in concert with increased ocean heat flux and wind mixing of the surface layer. A warmer atmosphere will lead to a warmer ocean, after some lag, and both will eventually have some impact on the polar ice sheets.

At this point, it is perhaps worthwhile to offer some orientation. We speak of "ice sheets" in the general sense. In truth, there exists an important distinction. There is floating ice and continental ice.

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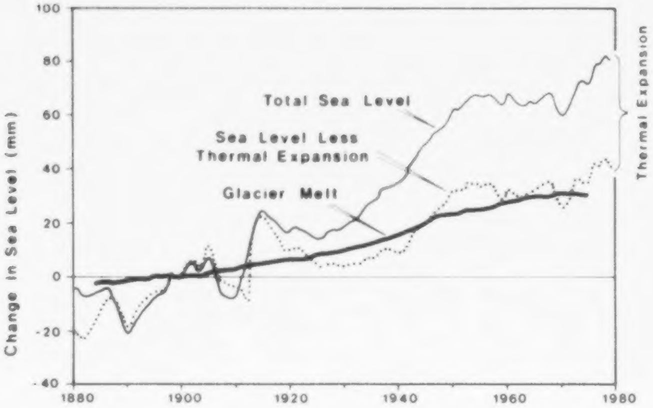

Figure 1. The role of thermal expansion in sea-level rise. Global sea-level change due to the melting of small glaciers is shown by the heavy solid line. Above it, the light line, is an estimated sea-level curve for increased atmospheric carbon dioxide, and subsequent rise in global ocean temperature. Subtracting the portion due to thermal expansion yields the dotted line curve. Thus, under these models, thermal expansion due to the warming of the oceans accounts for a substantial portion of the estimated sea-level rise. (After M. F. Meier, 1984)

The floating ice—the pack ice or sea ice of the Arctic, and the ice shelves of the Antarctic—represents large volumes of water, but since it is already floating, any melting will not change the sea level. A second distinction is worth noting here. The pack ice, or sea ice, of the Arctic is from the freezing of seawater, and is not considered under the term ice sheet. The ice shelves, on the other hand, are floating extensions of the continental ice sheets, and they form where ice flows into the sea.

The continental ice, ice based on land, once melted and drained (or calved and melted) into the ocean, may, on the other hand, cause a sea-level change. The continental ice is distributed as follows: Antarctica, 91 percent; Greenland, 8 percent; and mountain glaciers (for example, in Alaska and the Alps), 1 percent. The present view is that while a global warming may increase melting in Greenland, the quantity of water produced will have only a minor impact on sea level. Therefore, we turn our attention primarily to the Antarctic.

The West Antarctic Problem

If Antarctica's mantle of ice could be instantaneously removed, one would find in the eastern longitudes a rugged continent mostly above sea level (similar to Greenland) and an archipelago with deep submarine basins and continental shelves in the western longitudes (Figure 2). This West Antarctic ice sheet, equivalent to a global sea-level increase of 5 to 6 meters if melted, is grounded on the islands and basins and nearly surrounded by floating ice shelves.

The major portion of the ice sheet, including large parts of East Antarctica, drains through the ice shelves, which also retard the seaward progress of the outflowing ice streams. Thinning or removing these Texas-sized ice shelves would not change sea level, any more than a melting ice cube raises the level of the liquid in your cocktail glass. It could upset the dynamic regime of the ice sheet, however,

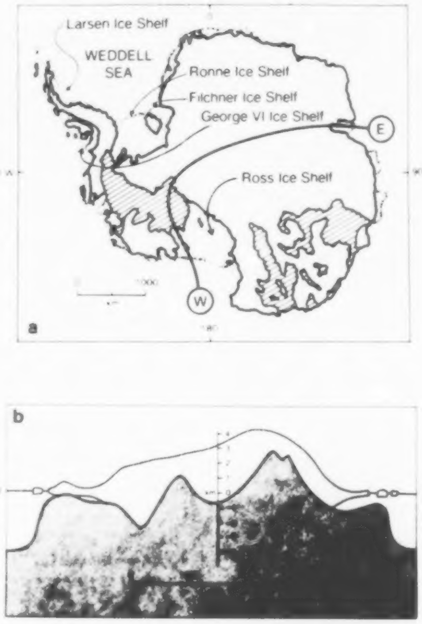

Figure 2. Antarctica, showing ice shelves (stippled) and areas where bedrock is more than 500 meters below sea level (hachured). A section along the bold line in 2a is shown in 2b, with the Ross Ice Shelf at left near the 180° meridian. The Filchner Ice Shelf is centered at 40° West. The Larsen and George VI Ice Shelves lie on the eastern and western sides of the Antarctic Peninsula, which is at 65° West. The ice is not static, but moving—at a few hundred meters per year—from higher elevations downslope to the ocean. (After Thomas and others, 1985.)

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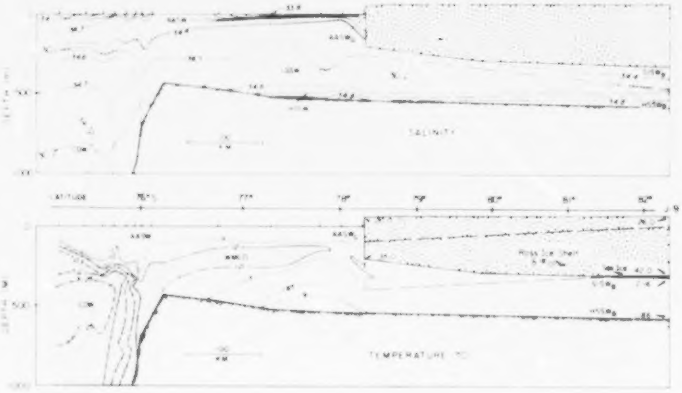

Figure 3. North-south vertical sections of salinity and temperature through the primary "warm" intrusion into the Ross Sea and beneath the Ross Ice Shelf. The lower diagram illustrates how the ice shelf may have been modified as it moves northward by surface accumulation and by basal melting and freezing. (In Oceanology of the Antarctic Continental Shelf, 1985)

causing grounding lines* to retreat into the submarine basins and allowing ice streams to surge into the sea. There is evidence for a 6-meter higher stand of sea level 125,000 years ago. On millenial time scales, large changes in sea level are believed to exert a major control over the Antarctic ice sheet configuration and dynamics. However, there is a general concensus that the inverse problem, polar meltwater raising sea level, would take several hundred years to achieve a major impact.

Stability of the Ice Shelves

If the West Antarctic ice sheet is sensitive to the stability of its ice shelves, how sensitive are the ice shelves to climatic warming? Summer surface melting is now inconsequential along most of the coastline, except for the western Antarctic Peninsula, but several degrees of atmospheric warming would increase the runoff. Surface meltwater generated during warm periods on the flat ice shelves would be likely to percolate into the snow and refreeze. Ice is a good insulator, so heat conduction from the atmosphere should be slow and have minor effects on glacier flow.

This allows us to dispel one of the common misconceptions about the melting and thinning of ice sheets. Indeed, the primary melting of floating ice comes from underneath rather than on top. The potentially vulnerable parts of the ice shelves are their vast basal areas, which are directly accessible to ocean heat flux. You may well ask why there would be any melting, since ice forms at the sea surface near ice shelves for much of the year, causing very cold (−1.9 degree Celsius), brine-enriched seawater to sink to great depths, where it is still found in summer. The primary reason is that the freezing point of seawater (T_p) decreases with increasing pressure, so that water overturned at the sea surface will be around 0.5 degrees Celsius above T_p at 700 meters depth. In addition to the melting potential afforded by this sensible heat bonus, the T_p depression may allow the redistribution of basal ice, with melting at depth followed by upwelling and deposition of ice at shallower levels.

Another mass balance factor is the circumpolar deep water, which has access to the ice shelf bases at various locations around the continent. In the Weddell Sea and Ross Sea, its access is now limited to cooled, mid-depth intrusions across the continental shelf (Figure 3). Adjacent to the southwest Antarctic Peninsula, however, nearly unaltered, +1.0 degree Celsius deep water penetrates beneath George VI Ice Shelf resulting in basal melting rates around 2 meters per year. A third reason to anticipate melting is that there is now known to be an active ocean circulation (and a functioning ecosystem) far beneath the largest ice shelves. The tidal and thermohaline circulations may regionally break down the stable stratification that would result from a layer of meltwater beneath the ice.

Deep temperature and current measurements along the northern front of the Ross Ice Shelf have disclosed large seasonal and interannual variability. During winter, temperatures are expectedly lower but current velocities are markedly higher. In a southward-flowing "warm" current, monthly heat flux was highest during July (midwinter). Topographic steering and isopycnal* access to the deep water appear to control the source and recirculation of this water in the Ross Sea. Annual heat flux into the sub-ice shelf cavity appears capable of melting a few tens of centimeters, averaged over the ice shelf base. This is consistent with glaciological models of the steady-state ice shelf flow and mass balance. Beneath the ice, melting probably varies from a few meters per year near the ice front to several centimeters per year near the grounding lines, but there are large sectors where basal freezing prevails.

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* Grounding lines mark the boundary between ice that is floating and ice that is grounded on the land or seafloor (see Figure 2). Removal of the buttressing ice shelves might allow ice streams that now feed the ice shelves to flow much faster, or "surge."

* An isopycnal is a surface of constant density.

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The Mass Budget of Antarctica

On the attrition side of Antarctica's mass budget, estimates of ice shelf melting range from 0 to 675 cubic kilometers per year, while iceberg calving has been said to lie between 500 and 2,400 cubic kilometers per year. Most calving estimates derive from censuses of iceberg populations, an art best practiced by the Soviets and Norwegians. After accounting for duplicate observations, iceberg life expectancies (several years), the difficulty of measuring dimensions, and the probable errors in extrapolating from subsamples to the entire Southern Ocean, one is left with the major problem of temporal variability. The white continent simply does not calve icebergs as regularly as a white leghorn lays eggs. For example, the western third of the Ross Ice Shelf front has apparently not experienced significant calving since before Amundsen and Scott trekked to the South Pole in 1911.

Ice shelf fronts in the Weddell Sea also had undergone decades of slow advance, until several large icebergs calved from the Larsen and Filchner Ice Shelves this year. The evidence suggests that the Weddell Sea breakout of 1986 does not represent a crisis event, such as the impending breakup of the ice sheets. Rather, indications are that what happened in the Weddell Sea this year has simply redressed a growing imbalance between advance and decay. The ice shelves of the region had been advancing slowly for decades. Accounts of the iceberg sizes differ, but they may contain substantially more water than the annual accumulation on the Antarctic continent.

On the accumulation side of the Antarctic mass budget, precipitation minus evaporation and snow blown off the ice is around 2,200 cubic kilometers per year (± 10 percent). A warmer atmosphere can transport more moisture, and global climate models tend to show a few tenths of a millimeter per day more rapid increase in precipitation than evaporation at high southern latitudes. That does not sound like much, but Antarctica is a desert in terms of its "rainfall," which averages around 16 centimeters per year. With other factors unchanged, an increase of 0.2 millimeters per day would correspond to 1,000 cubic kilometers per year, half the present accumulation rate and twice the present rate of sea-level rise. There is evidence for both warming and increased precipitation on Antarctica in recent decades, but the records are still too short to separate climatic trends from decadal cycles. In terms of the ice sheet/sea level relationship, the potential importance of an increase in precipitation is that it could postpone the day of reckoning if not reverse the sign of the change. In the interim, the oceans might have time to absorb more of the greenhouse gases, and man might be able to reduce his pollution of the atmosphere.

How to Play the Game

Current estimates of iceberg calving, basal melting, and freshwater runoff (in the Greenland case) inspire little confidence that we really know how close the polar ice sheets are at present to a state of mass balance. However, radar and laser altimeters aboard polar-orbiting satellites could help considerably to narrow the range of uncertainties. Changes in the ice sheet margins and other features can be monitored with altimeter data in conjunction with radio-echo sounding profiles (for thickness) and navigational transponders (for velocity). Further, the altimeters should be able to detect relevant elevation changes on the continent, since a 1 centimeter change of global sea level would roughly correspond to a 2 meter elevation change over the grounded portion of West Antarctica.

Large changes in ice shelf melting rates may be detectable in repeated thickness (elevation) profiles, but we also need to understand why there appear to be order-of-magnitude differences in melt rates between ice shelves. If a warmer atmosphere causes less sea ice formation on the continental shelves and less-dense shelf water, will that significantly change the shelf circulation or exchange with the deep ocean? Will global climate models with high latitude deep ocean convection, realistic sea ice cycles, and better-parameterized boundary layer processes show the same polar-amplified effects?

While ocean models are formulated and then tested by relevant long-term observations, particularly of salinity, it is worth reflecting on the risky geophysical game we are playing with the Earth's climate. Antarctica may be a wild card in this game, but who can say the deck is not stacked—with Nature setting up the sting?

Stanley S. Jacobs is a Senior Staff Associate at the Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York.

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What Impact Might Sea Level Rise Have?

ACTIVITY 14

Lesson Focus:

How might thermal expansion of the oceans affect sea level?

Objective:

The student will be able to:

1. Describe the change in water level when the water is exposed to heat.
2. Differentiate between thermal expansion and melting snow and ice fields as they relate to sea level rise.
3. Predict the impact of rising sea level on coastal areas.

Time:

1 Day

Grade Level:

8–10

Key Concepts:

Sea level rise, thermal expansion, ice and glacial melting

Definition of Terms:

Thermal Expansion: When most substances are heated, their volume increases due to increasing vibrations in their component molecules. In the case of oceanic thermal expansion, as the water molecules are warmed, the volume of water increases.

Sea Level: The level of the ocean surface water midway between high and low tide levels.

Land-Based Ice Fields: Ice fields that lie on top of land masses. Examples include mountain glaciers, the Antarctic ice sheet, and the Greenland ice sheet. Melting of these ice fields would add water to the ocean, thus raising sea level.

Floating Ice Caps: Packed ice that covers the sea surface. The Arctic Ocean is generally covered by floating ice caps. Melting of polar ice caps would not have an impact on sea level because this ice is already floating, thus displacing its volume in the water.

Background:

If global temperature increases, many scientists have indicated that an increase in sea level is one of the most likely secondary effects. Two factors will contribute to this accelerated rise in sea level. First, although the oceans have an enormous heat storage capacity, if global atmospheric temperatures rise, the oceans will absorb heat and expand (thermal expansion) leading to a rise in sea level. Second, warmer temperatures will cause the ice and snowfields to melt, thereby increasing the amount of water in the oceans. It should be noted that only the melting of land-based ice and snow fields (i.e., ice fields of Antarctica, mountain glaciers) will increase sea level. The melting of floating ice (i.e., North Polar ice cap) will not affect sea level. *[This can be demonstrated to your students by partially filling a glass container with water and ice cubes and marking the water level on the glass. When the ice cubes melt, note that the water level has not changed.]*

Throughout the Earth's history there have been periods of glaciation followed by warming trends in which the glaciers retreated toward higher altitudes and higher latitudes. At present, glaciers throughout the world are receding and the masses of ice at both polar regions appear to be shrinking. The present interglacial warming period began approximately 14,000 years ago. At that time, sea levels were 75 to 100 meters below present levels. As the massive snow and ice fields of the world began to melt, sea level rose rapidly at rates of as much as 1 meter per century. Over time, the rate of sea level rise declined to the present rate of 10 to 15 centimeters a century.

An accelerated rise in sea level would inundate coastal wetlands and lowlands, increase the rate of shoreline erosion, exacerbate coastal flooding, raise water tables, threaten coastal structures, and increase the salinity of rivers, bays, and aquifers. Even though sea level rise is considered to be one of the more likely effects of global warming, there's still no scientific certainty as to the rate or amount of sea level rise.

Activity:

The students will conduct an experiment that demonstrates the effect of thermal expansion on water level. Discussion groups will follow this activity as students explore the potential impact of sea level rise on a global and local scale.

Materials:

For each team of students:

- Conical flask
- Two-hole cork for flask
- Thin, glass tube
- Long thermometer
- Portable, clamp-on reflector lamp
- 150-Watt floodlight
- Dye

Procedure

1. Divide students into small teams.
2. ***Completely*** fill the flask with very cold water (to improve visibility, dye can be added).

3. Place the cork in the stopper. Slide the thermometer and glass tube in the holes in the cork (Figure 1). The water should rise a short way into the tube. Have students record both the temperature of the water and the water level in the glass tube in their log books.

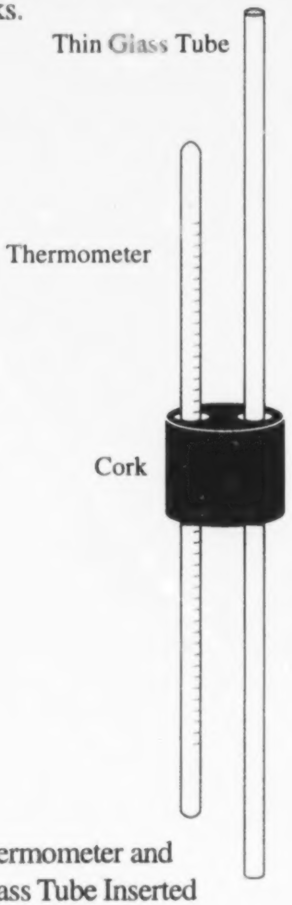
Thin Glass Tube
Thermometer
Cork

Figure 1. Thermometer and Glass Tube Inserted in Cork Holes

4. Ask students to predict what will happen to the water level when exposed to heat. Record prediction in logbook. Place the flask under the lamp (Figure 2). Turn on the lamp and record measurements every 2 minutes.

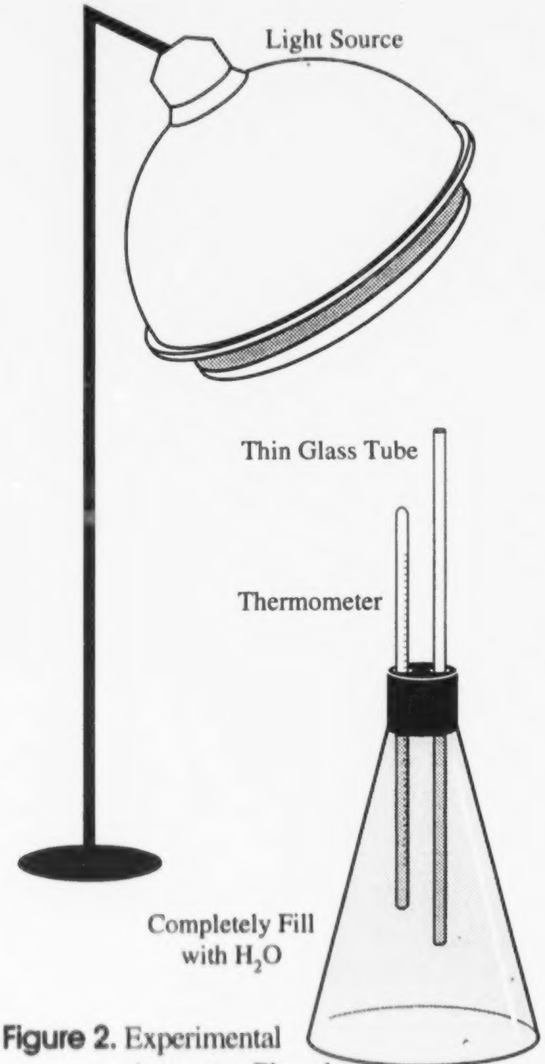
Light Source
Thin Glass Tube
Thermometer
Completely Fill with H_2O

Figure 2. Experimental Apparatus Placed Under the Light Source

Discussion:

- Why did the level of water in the flask change?

  As water warms, it expands.

- What implications does this experiment suggest might occur if the oceans warm?

  If the ocean temperatures warm sufficiently to cause expansion, sea level would rise thus inundating coastal wetlands and other coastal low-lying areas.

  Challenge your students to consider the possible impacts of sea level rise in areas such as South Florida or Bangladesh.

- If global warming is not sufficient to cause significant snow and ice melt, would you expect this thermal expansion to be enough to cause coastal flooding and erosion problems?

  No, it will likely be enough to measure, but not enough to cause significant coastal problems.

- Which would you expect to have a greater affect on sea level – the melting of the North Polar or South Polar ice caps?

  Would it make a difference? Why? North Polar melting would have little effect on sea level. That ice is already floating, thus displacing its volume in water. If the South Polar ice cap melted, the water would run off the Antarctic continent into the ocean, increasing the ocean volume (and sea level) substantially.

  Challenge your students to design an experiment using ice cubes to test this idea.

Student Learning Portfolio:

1. Graph of the thermal expansion experiment
2. A summary of the discussion questions in lab notebook ☐

Notes:

What Impact Might Sea Level Rise Have?

STUDENTGUIDE—ACTIVITY 14

Definitions of Terms:

Thermal Expansion: When most substances are heated, their volume increases due to increasing vibrations in their component molecules. In the case oceanic of thermal expansion, as the water molecules are warmed, the volume of water increases.

Sea Level: The level of the ocean surface water midway between high and low tide levels.

Land-Based Ice Fields: Ice fields that lie on top of land masses. Examples include mountain glaciers, the Antarctic ice sheet, and the Greenland ice sheet. Melting of these ice fields would add water to the ocean, thus raising sea level.

Floating Ice Caps: Packed ice that covers the sea surface. The Arctic Ocean is generally covered by floating ice caps. Melting of polar ice caps would not have an impact on sea level because this ice is already floating, thus displacing its volume in the water.

Activity:

You will conduct an experiment that demonstrates the effect of thermal expansion on water level. Discussion groups will follow this activity as you explore the potential impact of sea level rise on a global and local scale.

Materials:

For each team of students:

- Conical flask
- Two-hole cork for flask
- Thin, glass tube
- Long thermometer
- Portable, clamp-on reflector lamp
- 150-Watt floodlight
- Dye

Procedure:

1. Working with your team, completely fill the flask with very cold water (for increased visibility, dye can be added to the water).
2. Place the cork in the stopper. Slide the thermometer and glass tube in the holes in the cork (Figure 1). The water should rise a

short way into the tube. Record both the temperature of the water and the water level in the glass tube in your log books.

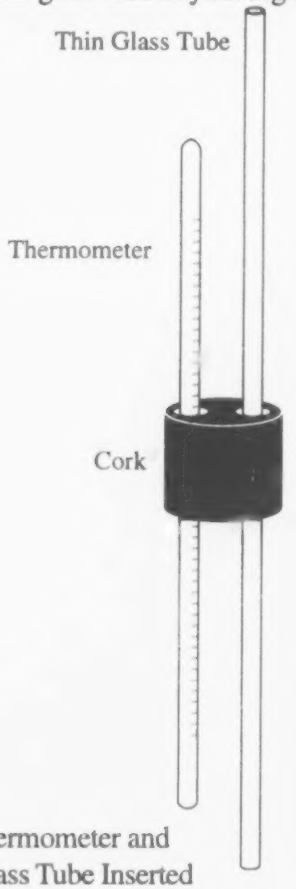

Figure 1. Thermometer and Glass Tube Inserted in Cork Holes

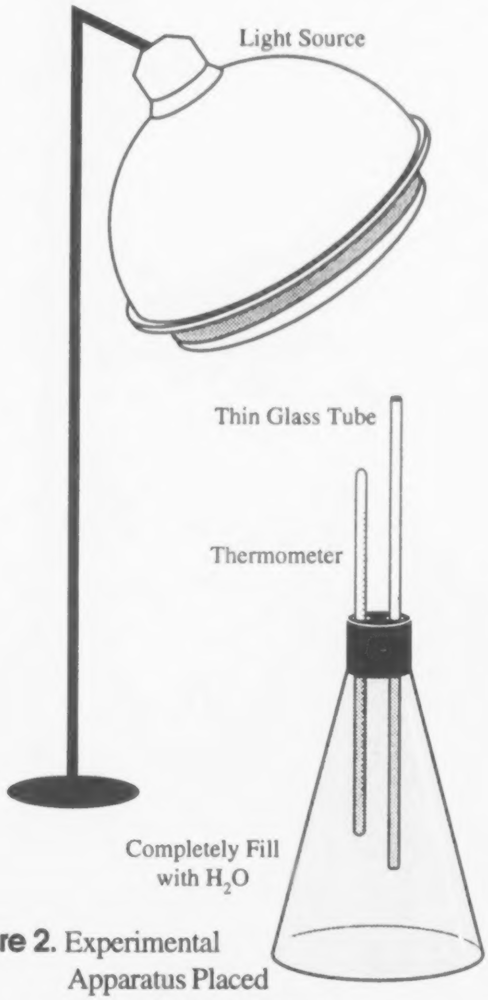

Figure 2. Experimental Apparatus Placed Under the Light Source

3. What do you think will happen to the water level when exposed to heat? Record your prediction in your logbook.
4. Place the flask under the lamp (Figure 2). Turn on the lamp and record measurements every 2 minutes.

Discussion:

- Why did the level of water in the flask change?
- What implications does this experiment suggest might occur if the oceans warm?
- If global warming is not sufficient to cause significant snow and ice melt, would you expect this thermal expansion to be enough to cause coastal flooding and erosion problems?
- Which would you expect to have a greater affect on sea level — the melting of the North Polar or South Polar ice caps?❑

Sea-Level Rise

Reprinted with permission from *Interpreting Current Research on Global Environmental Issues for Middle School Teachers and Their Students*, National Science Foundation Grant # TPE 9055398, Gulf Coast Research Laboratory, 1993, Ocean Springs, Mississippi.

NAME: Frank Abdulla
SCHOOL: Bradford Middle
SCHOOL DISTRICT: Bradford County, Florida
GRADE/SUBJECT: Eighth Physical Science

1) TOPIC AND ISSUE STATEMENT: Sea Level Rise. Sea Level Rise is caused by natural and anthropogenic factors such as global warming, greenhouse effect, ozone depletion, and deforestation. As an example, scientists believe that the massive harvesting of tropical trees in the Amazon region of South America could cause an increase of 3 to 5 degrees Celsius in the average temperature of the globe. Such an event would cause ice deposits on land and in the seas to melt, thus causing sea levels to rise. Rising sea level has many consequences such as, loss of habitat, structures, arable land loss, coastal areas, and relocation of people.

OBJECTIVES:

(1) Students will be able to observe that higher temperatures which will cause rapid melting of ice.

(2) Students will be able to infer, from his/her observations in the laboratory activity, that warming the atmospheric air will cause more ice to melt in nature, thereby causing sea level rise.

MATERIALS: Two clear containers, handy wrap, rocks, sand, thermometers and ice.

REFERENCES: William C. Brown, Inquiry Into Life.
Video, "The Greenhouse Effect," Summit Learning, Box 493 G, Ft. Collins, CO 80522.
Charts of Sea Level Rise at two different locations.

STRATEGY: This is the laboratory activity that will be conducted after the students have viewed the video concerning the greenhouse effect, followed by class discussion. The students will be divided into six groups; each group is directed to investigate the temperature change and its effect on sea level rise.

ACTIVITIES:

(1) Students will view the video, "The Greenhouse Effect," and engage in a class discussion.

(2) Students will be divided into six groups, each to investigate the interaction between temperature change and ice melting.

(3) The experiment should be conducted as follows:

  (a) Each group will use two, plastic (clear) containers and place the same amount of rocks and sand inside the containers along with the same amount of water and ice.

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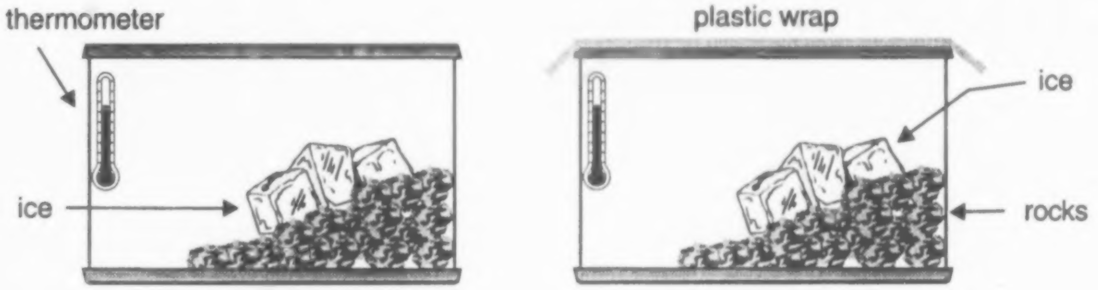
(b) One thermometer will be placed in each container. (See diagram below)



(c) One container will resemble the greenhouse effect while the other is the control. Both containers will be placed under direct sunlight. One container will be covered with handy wrap completely. The remaining container will be the uncovered and serve as the "control."

(d) Students will use the following chart to record their observations

	No Cover:		**With Cover:**	
Time Start	Temperature	Ice Melt	Temperature	Ice Melt
5 minutes				
10 minutes				
15 minutes				
20 minutes				

POSSIBLE EXTENSION:

(1) Students will graph sea level rise through the past 30 thousand years.
(2) Students will show tide changes in the coastal areas in Florida.
(3) Students may investigate the impact of sea level rise on the U.S. economy.

TEACHER'S EVALUATION:

(1) After collecting the data, each student will write a report, using the scientific method, interpreting the data, and developing a conclusion.

(2) When asked, students should be able to point out that sea level rising is caused by melting of ice due to global warming.

(3) Students should be able to explain the concept of sea level rise by relating the melting of the ice in the container that was covered with the handy wrap as a simulation of what is occurring in nature. Students will graph the data to quantify it. (The higher the temperature, more ice will have melted and caused higher levels of water observed in the containers).

Saltwater Intrusion

NAME:	Anne B. Rhodes
SCHOOL:	Biggersville Elementary
SCHOOL DISTRICT:	Alcorn, Corinth, Mississippi
GRADE/SUBJECT:	Sixth Grade Science

Reprinted with permission from *Interpreting Current Research on Global Environmental Issues for Middle School Teachers and Their Students*, National Science Foundation Grant # TPE 9055398, Gulf Coast Research Laboratory, 1993, Ocean Springs, Mississippi.

(1) TOPIC AND ISSUE STATEMENT:

Does it really matter if some organisms in an ecosystem are eliminated? Couldn't we do without the pesky fly or the destructive clothes moth or the fire ant? With all our efforts to get rid of them, they adapt and survive. They are all part of a food web, as are all other animals. There are many steps being taken to preserve biodiversity. Perhaps the best method would be to outlaw the destruction of relatively undisturbed lands.

(2) OBJECTIVE:

The learner will predict the growth of a water plant in a freshwater biome and a saltwater biome and compare the actual results.

RESOURCE:

a) Scott Foresman, Discover Science 1989, 6th grade
b) "Conservation: Tactics for a Constant Crisis" by Soule
c) "The Sinking Ark" by McNeely

MATERIALS:

For each group, 2 jars, freshwater, saltwater, 2 elodea plants, aquarium gravel.

STRATEGY:

After students have discussed the food web, the energy pyramid and the importance of the balance of a biome for it to survive, this activity will show students how man can be a threat to the existence of a biome. Near estuaries, people are removing freshwater for drinking water. This allows saltwater to move farther inland. This can kill organisms living in the estuary, especially plants. This activity will illustrate this concept.

ACTIVITY:

The students will be divided into groups of three or four. Each group will put a layer of gravel in the bottom of two jars. Into one jar put fresh water and put saltwater into the other. Label each jar. Place an elodea plant in each jar. Place both jars in the sunlight. Students will predict what will happen to each plant during the next five days and record their predictions. They will observe the plants each day and record observations. After the fifth day, students will determine to which environment the elodea is best adapted and make inferences as to what happens when an organism's normal environment is disrupted.

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EXTENSIONS:

a) Students may try the same experiment using controlled and polluted water. (with soap, pesticides, and other related compounds)

b) Students may consult a Fish and Game representative to determine which organisms are being endangered in their area.

c) Students could choose an extinct animal and research reasons for its extinction.

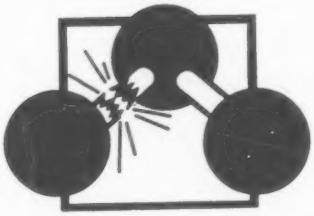
TEACHER EVALUATIONS:

a) How did your observation of elodea in fresh water compare with its growth in saltwater?

b) To which biome is elodea adapted? How do you know?

c) What do you think would happen if you put a goldfish in a saltwater aquarium?

IV



OZONE DEPLETION

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Volume 29, Number 1, Spring 1992, pp. 10-16,
Heldref Publications, Washington, D.C.

Ozone, Climate, and Global Atmospheric Change

JOEL S. LEVINE

The delicate balance of the gases that make up our atmosphere allows life to exist on Earth. Ozone depletion and global warming are related to changes in the concentrations of these gases. To solve global atmospheric problems, we need to understand the composition and chemistry of the Earth's atmosphere and the impact of human activities on them.

The Composition of the Earth's Atmosphere

The atmosphere of our planet contains several hundred different gases of diverse origins. However, about 99.96 percent of the total mass of the atmosphere is due to the presence of three major permanent constituents: nitrogen (N_2), 78.08 percent by volume; oxygen (O_2), 20.95 percent by volume; and argon (Ar), 0.93 percent by volume. Water vapor (H_2O), an atmospheric gas with a variable concentration, ranges by volume from a small fraction of a percent up to 1 or 2 percent.

NASA

The Earth photographed by the Apollo 17 astronauts in December 1972 during the final manned mission to the moon. The Antarctic ice cap is brightly illuminated. Two of the key elements that control the climate appear in the photograph: clouds and the oceans.

The remaining constituents of the atmosphere are trace gases whose atmospheric abundances are too low to be measured by percent (a unit of measure that is the same as parts per hundred by volume). Instead, the concentrations of the trace gases are measured in terms of *mixing ratio*—the number of molecules of the trace gas divided by the number of total atmospheric molecules (nitrogen, oxygen, argon, and all the others) in one cubic centimeter of air. Trace gases such as ozone (O_3), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and halons (brominated CFCs) are measured in parts per million by volume (ppmv), parts per billion by volume (ppbv), or parts per trillion by volume (pptv). The concentrations of the major and

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JOEL S. LEVINE, Senior Research Scientist, Theoretical Studies Branch, Atmospheric Sciences Division, NASA Langley Research Center, Hampton, Virginia, was selected as Virginia's Outstanding Scientist for 1987. Also a recipient of the NASA Medal for Exceptional Scientific Achievement, Dr. Levine wrote the lead article in the February-March 1981 issue of *Science Activities*, entitled "The Early Atmosphere: A New Picture." In addition, Dr. Levine edited and contributed to *The Photochemistry of Atmospheres: Earth, the Other Planets, and Comets*, published by Academic Press, Inc., in 1985, and *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications*, published by the MIT Press, Inc., in 1991.

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Table 1. Major and Selected Trace Gases in the Atmosphere

Gases	Concentration
Nitrogen (N_2)	78.08 percent by volume
Oxygen (O_2)	20.95 percent by volume
Argon (Ar)	0.93 percent by volume
Water vapor (H_2O)	0 to 1 or 2 percent by volume
Carbon dioxide (CO_2)	350 ppmv
Ozone (O_3)	
In troposphere	0.02 to 0.1 ppmv
In stratosphere	0.1 to 10 ppmv
Methane (CH_4)	1.7 ppmv
Nitrous oxide (N_2O)	0.31 ppmv
CFC-12 (CF_2Cl_2)	0.5 ppbv
CFC-11 ($CFCl_3$)	0.3 ppbv
Halon-1301 ($CBrF_3$)	2.0 pptv
Halon-1211 ($CBrClF_2$)	1.7 pptv
Hydroxyl (OH)	
In troposphere	0.015 pptv
In stratosphere	0.02 pptv to 0.3 ppbv
Nitric Oxide (NO)	
In troposphere	0 to 1 ppbv
In stratosphere	Up to 0.02 ppmv

Note: The concentrations of atmospheric gases are given in either percentage by volume (which is the same as parts per hundred by volume), parts per million by volume (ppmv), parts per billion by volume (ppbv), or parts per trillion by volume (pptv).

selected trace gases in the atmosphere are summarized in table 1.

It is an interesting and somewhat ironic fact that the chemistry of the atmosphere and the temperature of our planet are not controlled by the major gases, but rather by the trace gases. There is growing evidence that the trace-gas composition of the atmosphere is changing. The environmentally significant trace gases are affected by both natural and human-produced gases. Among these gases are the chlorofluorocarbons, human-made gases such as CFC-11 and CFC-12 that are used as propellents in aerosol spray cans; halons used in fire extinguishers; and carbon dioxide, nitrous oxide, and methane, which are produced by the burning of fossil fuels and living and dead biomass and by the metabolic processes of microorganisms in the soil, wetlands, and oceans of our planet.

The Origin of Atmospheric Ozone

The development of the atmospheric ozone layer had a very significant impact on the evolution of life on our planet. Throughout most of its 4.6 billion-year history, there was an insufficient level of ozone in the atmosphere to shield the Earth's surface from the biologically lethal ultraviolet radiation (electromagnetic radiation between 200 and 300 nanometers) emitted by the Sun. Before the development of the atmospheric ozone layer, life was restricted to the ocean depths where several meters of seawater absorbed the solar ultraviolet radiation and offered protection to the earliest forms of life on our planet.

About 600 million years ago, oxygen built up in the atmosphere to about 10 percent of its present atmospheric level as a result of photosynthetic activity. At this point, ozone, which is chemically formed from oxygen, reached sufficient levels in the atmosphere to effectively absorb incoming solar ultraviolet radiation, and, for the first time, living organisms could leave the safety of the ocean and live on land.

Ozone (O_3), composed of three oxygen atoms via atmospheric photochemical and chemical reactions, is a trace atmospheric gas. About 90 percent of the total atmospheric content of ozone is located in a layer between about 15 and 50 kilometers above the Earth's surface in the atmospheric region known as the stratosphere (see figure 1).

Changes in the Ozone Layer

The Antarctic Ozone Hole

Recent ground-based, aircraft, and satellite measurements have indicated an alarming trend in the level of ozone in the stratosphere over the Antarctic. These measurements indicate that, for more

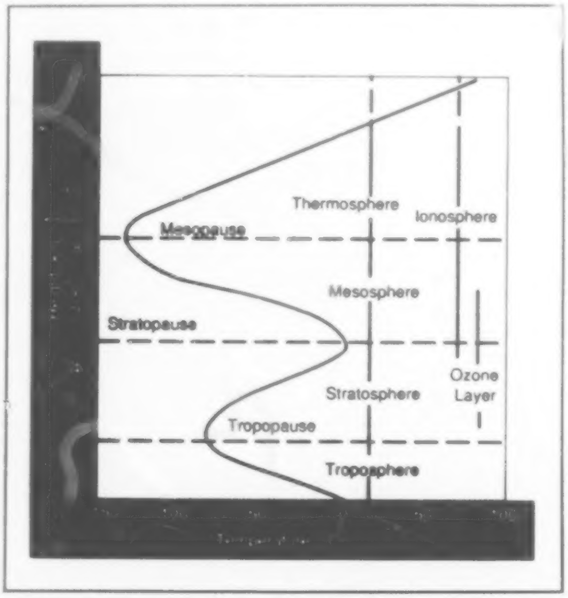

Figure 1. The structure of the Earth's atmosphere illustrating the various regions. Each region is defined by its temperature gradient. (Earth Systems Sciences Committee, NASA, 1988)

than a decade, during a specific period each year, the levels of ozone in the stratosphere have decreased by more than 50 percent. The so-called "hole" in the ozone layer is produced each year during a 4- to 6-week period, beginning in late September, which is the start of spring in the Southern Hemisphere. The area of the Antarctic ozone hole, about the size of the continental United States, has grown larger each year during this period.

Four to six weeks after the first appearance of the Antarctic ozone hole, ozone from the Southern Hemisphere mid-latitudes is transported to the South Pole by the general circulation patterns of the atmosphere and replenishes the missing gas. Then the following spring the hole reappears.

Global Changes in Stratospheric Ozone

Is there evidence for stratospheric ozone depletion outside of the Antarctic region? The Ozone Trends Panel, formed by NASA in October 1986, in collaboration with the National Oceanic and Atmospheric Administration, the Federal Aviation Administration, the World Meterological Organization, and the United Nations Environment Program has reanalyzed and reassessed the data on ozone abundances collected by the 30-year-old network of ground-based Dobson spectrophotometers concentrated in the Northern Hemisphere and by satellite instruments operating since the late 1970s.

In March 1988, the panel reported their findings: global levels of stratospheric ozone had fallen several percentage points between 1969 and 1986. The panel concluded that between 30°N latitude and 64°N latitude, from 1969 to 1986, stratospheric ozone decreased between 1.7 and 3.0 percent. The larger decreases occurred at the high latitudes in winter; the smaller drops occurred in summer.

There is other evidence to suggest that concentrations of ozone in the troposphere (the lowest atmospheric layer that extends from the surface to the beginning of the stratosphere and contains the remaining 10 percent of atmospheric ozone) have been increasing by about 1 percent per year over the past 20 years. This means that the decreases in stratospheric ozone probably exceed those for the total column content, which is the sum of tropospheric and stratospheric ozone.

What Is Destroying the Ozone?

The Ozone Trends Panel attributed the observed decreases in stratospheric ozone to increasing atmospheric levels of chlorofluorocarbons (see figure 2). The chlorofluorocarbons, Freon-11 ($CFCl_3$) and Freon-12 (CF_2Cl_2), are usually referred to as CFC-11 and CFC-12, respectively.

The major source of atmospheric CFC-11 and CFC-12 is the aerosol spray can, which uses these chemically inert gases as propellents. CFCs are also used as refrigerants in home and automobile air conditioners and in the manufacturing of closed-cell and open-cell foams.

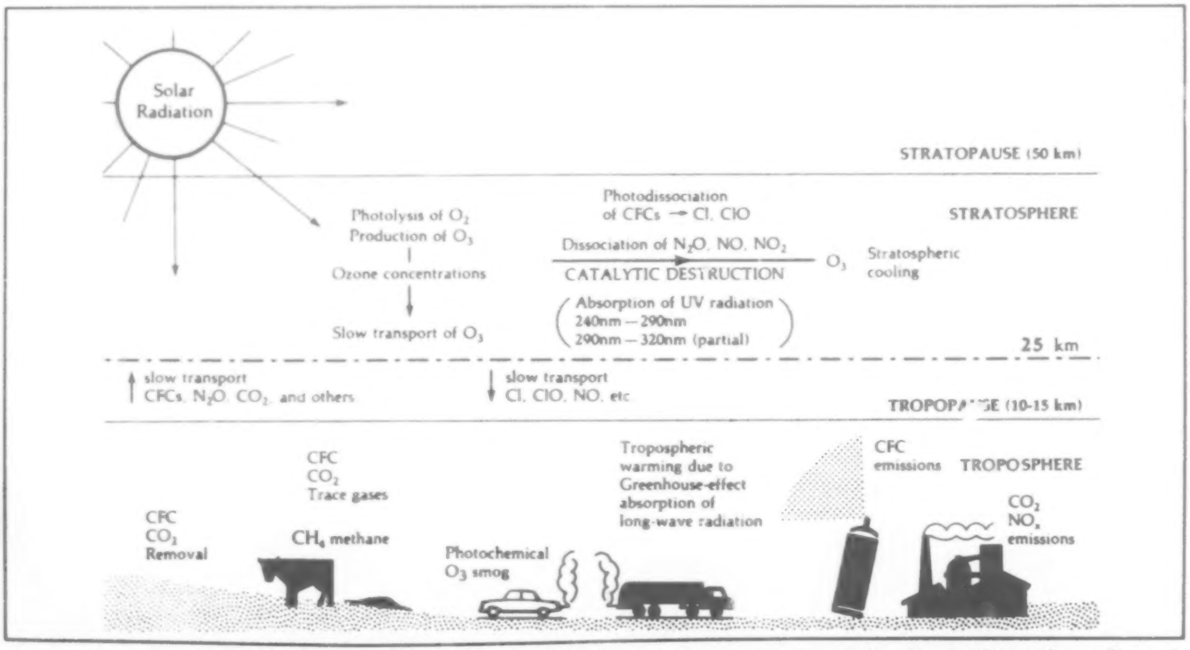
Solar Radiation
STRATOPAUSE (50 km)
Photolysis of O_2
Production of O_3
Ozone concentrations
Slow transport of O_3
Photodissociation of CFCs → Cl, ClO
Dissociation of N_2O, NO, NO_2
CATALYTIC DESTRUCTION
O_3
Stratospheric cooling
STRATOSPHERE
Absorption of UV radiation
240nm — 290nm
290nm — 320nm (partial)
25 km
slow transport
CFCs, N_2O, CO_2, and others
slow transport
Cl, ClO, NO, etc
TROPOPAUSE (10-15 km)
CFC
CO_2
Trace gases
CFC
CO_2
Removal
CH_4 methane
Photochemical
O_3 smog
Tropospheric warming due to Greenhouse-effect absorption of long-wave radiation
CFC emissions
TROPOSPHERE
CO_2
NO_x
emissions

Figure 2. A schematic illustrating some sources and sinks for greenhouse gases and the chemical transformations of these gases in the troposphere and stratosphere. (International Geosphere-Biosphere Programme, 1990)

Additional trace gases that destroy ozone in the stratosphere by chemical reactions include bromine (Br), nitric oxide (NO) and the hydroxyl radical (OH). Methane reactions produce the water vapor that releases the hydroxyl radical in the stratosphere.

Ozone Depletion Caused by Chlorine and Bromine

The cause of the Antarctic ozone hole is now believed to be the chlorine and bromine originally released from the CFCs and halons, or brominated CFCs. These two elements are released into the atmosphere through a series of reactions.

Chlorine atoms are liberated in the stratosphere by the action of solar radiation on CFC-11 and CFC-12 molecules, the only significant source of chlorine atoms in the stratosphere. The ice clouds that form in the dry, frigid, isolated Antarctic stratosphere greatly facilitate the chemical reactions that free chlorine atoms from the reservoir compounds, where they reside after being released from the CFCs. Then the chlorine is readily available to chemically destroy ozone in the Antarctic stratosphere after the long, cold Antarctic winter.

Atmospheric levels of CFC-11 and CFC-12 are about 0.3 ppbv and 0.5 ppbv, respectively. The levels of each of these gases is increasing at a rate of about 5 percent per year. The atmospheric lifetimes (the time before the gas is destroyed or lost to the atmosphere) of CFC-11 and CFC-12 are about 65 and 130 years, respectively.

After warnings about stratospheric ozone depletion caused by CFCs, the United States banned the use of these gases in aerosol spray cans in 1978. Unfortunately, the rest of the world did not. However, in September 1987, representatives from more than thirty nations signed the Montreal Protocol, which froze CFC production rates at 1986 levels after 1989 and will cut them in half by 1999. In 1990, in London, the provisions of the original 1987 Montreal Protocol were strengthened by the participating countries. This will lead to a more rapid phaseout of aerosol spray CFCs and halons. Nevertheless, because of their very long atmospheric lifetimes, the impact of the CFCs and halons already released will still be felt for many years following their phaseout.

Also implicated in the springtime chemical destruction of ozone over the Antarctic is bromine (Br). Human-produced sources of bromine include the halons, or brominated CFCs, such as bromotrifluoromethane (Halon-1301: $CBrF_3$) and bromochlorodifluoromethane (Halon-1211: $CBrClF_2$). Bromine monoxide (BrO), produced from Halon-1301 and Halon-1211, reacts with chlorine monoxide (ClO), produced from CFCs, to release bromine (Br) and chlorine (Cl), both of which destroy ozone in the stratosphere.

Most halons are used as fire-extinguishing agents. The atmospheric concentrations of Halon-1301 and 1211 are only 2 pptv and 1.7 pptv, respectively. However, their atmospheric levels are increasing at rates of 15 percent and 12 percent per year, respectively. The atmospheric lifetime of Halon-1301 is about 110 years; that of Halon-1211, about 25 years.

Ozone Depletion Caused by Nitric Oxide

Molecules of nitric oxide also destroy stratospheric ozone. These molecules are produced by the chemical transformation of nitrous oxide in the stratosphere. Most nitrous oxide is produced by bacteria in natural and fertilized soils during the processes of nitrification and denitrification.

The surface concentration of nitrous oxide is about 0.31 ppmv. Measurements indicate that nitrous oxide is increasing about 0.2 to 0.3 percent per year. The atmospheric lifetime of nitrous oxide is about 150 years.

Effects of Ozone Depletion

Calculations indicate that for each one percent decrease in atmospheric ozone, the amount of solar ultraviolet radiation reaching the ground will increase by 2 percent. It is estimated that a 2 percent increase in solar ultraviolet radiation could increase future skin cancer cases by 3 to 6 percent each year. There are presently about 500,000 cases of skin cancer diagnosed each year in the United States.

It has also been suggested that solar ultraviolet radiation can damage the human immune system, cause billion of dollars worth of crop damage, and adversely affect plankton in the ocean, the base of the marine food chain.

What Is the Greenhouse Effect?

Another change in the atmosphere that is affecting our climate is the increasing concentrations of greenhouse gases. This buildup of greenhouse gases results in a greater warming of the Earth's surface.

Greenhouse gases have the ability to absorb, or trap, upward-moving infrared radiation, heat energy, emitted by the Earth's surface (see figure 3). The greenhouse gases quickly reemit, or release, the absorbed heat energy with approximately 50 percent of the reemitted energy directed back toward the Earth's surface. This heat energy would have been lost to space if it had not been trapped by greenhouse gases.

Ozone, Methane, Nitrous Oxide, and the CFCs as Greenhouse Gases

While ozone in the stratosphere is decreasing, measurements indicate that ozone, as well as other trace gases, is increasing in the troposphere. It is ironic that, while ozone in the stratosphere is bene-

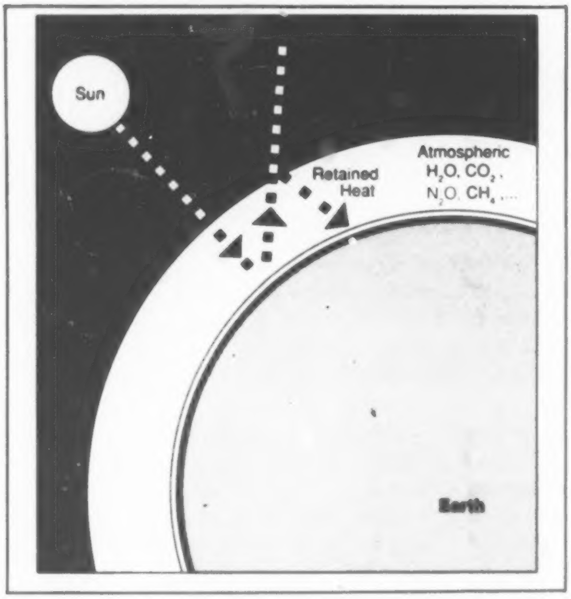

Figure 3. The greenhouse effect results from the fact that the atmosphere is transparent to incoming solar radiation, but absorbs and reemits infrared radiation emitted at the surface. This effect is made stronger by increasing concentrations of water vapor, carbon dioxide, nitrous oxide, and methane. (Earth Systems Sciences Committee, NASA, 1988)

ficial to human health and survival, tropospheric ozone in high concentrations is a pollutant that is harmful to human, animal, and plant life.

In the troposphere, ozone is chemically formed from the combustion products of fossil fuel burning, including automobile exhaust gases, and the combustion products of biomass burning. Increasing trace gases in the troposphere, in addition to ozone, include carbon dioxide, methane, nitrous oxide, and the chlorofluorocarbons CFC-11 and CFC-12 (see figure 4). All six of these gases are greenhouse gases.

Water Vapor as a Greenhouse Gas

Water vapor is the most important atmospheric greenhouse gas. The water vapor concentration of the troposphere, where almost all of the water vapor in the atmosphere is located, is controlled by atmospheric temperature and the evaporation and condensation cycle. At present, atmospheric water vapor concentrations do not appear to be changing as a result of human activities.

Carbon Dioxide as a Greenhouse Gas

After water vapor, carbon dioxide is the most important greenhouse gas. The surface concentration of carbon dioxide is about 350 ppmv. Measurements indicate that carbon dioxide is increasing by about 0.5 percent per year.

Carbon dioxide is chemically inert in the atmosphere. Hence, there are no significant atmospheric reactions that form sinks, or repositories, for carbon dioxide. The sinks for carbon dioxide include uptake and incorporation in the living biosphere during photosynthetic activity, dissolution in the ocean with the subsequent formation of carbonate rocks (limestone, calcite, dolomite, etc.) and the build-up of the gas in the atmosphere.

Carbon dioxide is produced by biological respiration on land and in the ocean and by the burning of fossil fuels and living and dead biomass. It is interesting to note that the bulk of the burning of fossil fuels occurs in the industrialized or developed countries, while almost all of the biomass burning takes place in the Third World developing countries of South America, Africa, and Asia.

The Double Whammy of Deforestation

Deforestation by burning, a widespread practice in the world's tropical rain forests, adversely impacts the trace-gas composition of the atmosphere in two different ways. First, the burning of the tropical forests produces large amounts of carbon dioxide, carbon monoxide (CO), methane, and other trace gases that are the combustion products of biomass burning. Second, the tropical forest is an important sink, or repository, for carbon dioxide. Atmospheric carbon dioxide is incorporated into the living biomass via the process of photosynthesis, which in turn produces atmospheric oxygen.

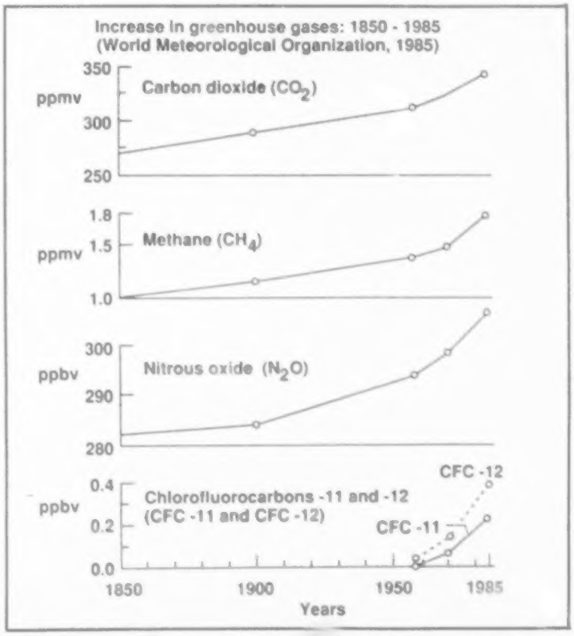

Figure 4. The increase in atmospheric concentrations of greenhouse gases from 1850 to 1985. (World Meteorological Organization, 1985)

Ozone Update

In October 1991, the most recent assessment of stratospheric ozone, entitled the Scientific Assessment of Stratospheric Ozone—1991, was finalized. The study was coordinated by the United Nations Environmental Program (UNEP), the World Meteorological Organization (WMO), the United Kingdom Department of the Environment, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). The report of the results and implications of this study is just now coming out. Because of the timeliness of this new scientific assessment and its relevance to this article, I have excerpted the following major points from the executive summary.

EXCERPTS FROM THE EXECUTIVE SUMMARY

Latest Assessments

Global Ozone Decreases: Ground-based and satellite observations continue to show decreases of total column ozone in winter in the northern hemisphere. For the first time, there is evidence of significant decreases in spring and summer in both the northern and southern hemispheres at middle and high latitudes, as well as in the southern winter. No trends in ozone have been observed in the tropics. These downward trends were larger during the 1980s than in the 1970s. The observed ozone decreases have occurred predominantly in the lower stratosphere.

Polar Ozone: Strong Antarctic ozone holes have continued to occur and, in four of the past five years, have been deep and extensive in area. This contrasts to the situation in the mid-1980s, where the depth and area of the ozone hole exhibited a quasi-biennial modulation. Large increases in surface ultraviolet radiation have been observed in Antarctica during periods of low ozone. While no extensive ozone losses have occurred in the Arctic comparable to those observed in the Antarctic, localized Arctic ozone losses have been observed in winter concurrent with observations of elevated levels of reactive chlorine.

Ozone and Industrial Halocarbons: Recent laboratory research and re-interpretation of field measurements have strengthened the evidence that the Antarctic ozone hole is primarily due to chlorine- and bromine-containing chemicals. In addition, the weight of evidence suggests that the observed middle- and high-latitude ozone losses are largely due to chlorine and bromine. Therefore, as the atmospheric abundances of chlorine and bromine increase in the future, significant additional losses of ozone are expected at middle latitudes and in the Arctic.

Implications for Policy Formulations

The findings and conclusions of the research of the past few years may have several major implications on policy decisions regarding human-influenced substances that lead to stratospheric ozone depletions and to changes in the radiative forcing of the climate system.

Continued Global Ozone Losses: Even if the control measures of the amended Montreal Protocol (London, 1990) were to be implemented by all nations, the current abundance of stratospheric chlorine (3.3-3.5 ppbv) is estimated to increase during the next several years, reaching a peak of about 4.1 ppbv around the turn of the century. With these increases, the additional middle-latitude ozone losses during the 1990s are expected to be comparable to those observed during the 1980s, and there is the possibility of incurring wide-spread losses in the Arctic. Reducing these expected ozone losses requires further limitations on the emissions of chlorine- and bromine-containing compounds.

Approaches to Lowering Global Risks: Lowering the peak and hastening the subsequent decline of chlorine and bromine levels can be accomplished in a variety of ways, including an accelerated phase-out of controlled halocarbons.

Elimination of the Antarctic Ozone Hole: If all nations were to fully comply with the phase-out schedule of the amended Montreal Protocol, and if all uses of hydrochlorofluorocarbons (HCFs) [hydrogen-containing CFCs that are more chemically active and hence shorter-lived than other CFCs] were discontinued, then it is estimated that stratospheric chlorine abundances would return to 2 ppbv sometime between the middle and the end of the next century. This is the level at which the antarctic ozone hole appeared in the late 1970s and hence, is the level that is considered necessary (assuming other conditions are constant, including bromine loading) to eliminate the ozone hole. Such levels could never have been reached under the provisions of the original Protocol (Montreal, 1987).

The statistics on the loss of the world's tropical rain forests are staggering. Less than 60 percent of the originally forested land in the tropics remains. Most of the destruction of the tropical forests by burning has taken place in the last 30 years. Deforestation rates are about 28 million acres a year, or about 50 acres a minute. At that rate, what remains of the world's tropical rain forests could be reduced by half in less than 50 years and be totally gone within 100 years.

The amount of carbon dioxide and other trace gases produced during biomass burning on a global scale is not precisely known. For one thing, there is very little information available on the type and concentration of gases produced by biomass burning in the rest of the world's very diverse ecosystems, such as mid-latitude and northern latitude forests and wetlands. A recent report by the National Academy of Sciences indicates that biomass burning may cover as much as 5 percent of the total land area of our planet each year.

Methane as a Greenhouse Gas and Ozone Depleter

Another carbon-containing greenhouse gas is methane. The surface concentration of methane is about 1.7 ppmv. Atmospheric measurements indicate that methane is increasing about 1.0 percent per year. Most methane is produced by microorganisms in anaerobic, oxygen-deficient, environments. The major global sources of methane are wetlands, swamps, and rice paddies (all strongly anaerobic environments). Other major sources of methane are enteric fermentation in cattle, natural gas and mining losses, and biomass burning.

Unlike carbon dioxide, methane is chemically active in both the troposphere and stratosphere. In the troposphere, the reaction between methane and the hydroxyl radical (OH) leads to the chemical production of ozone, which is a greenhouse gas.

In the stratosphere, methane is an important source of water vapor. The hydroxyl radical formed from the chemical transformation of water vapor leads to the destruction of stratospheric ozone. On the other hand, methane reactions also decrease the effectiveness of chlorine and nitric oxide in the destruction of stratospheric ozone.

Possible Effects of Greenhouse Gases

Theoretical calculations of climate change are often made by using computer models that project the effect of the increasing concentrations of greenhouse gases. It should be emphasized that the climate is a very complex and not completely understood system that is controlled and regulated by incoming solar radiation, outgoing Earth-emitted radiation, clouds, the oceans, and the evaporation and precipitation cycle, as well as by atmospheric greenhouse gases.

Temperature Increases Caused by Greenhouse Gases

Theoretical climate calculations indicate that a doubling of atmospheric carbon dioxide could increase the global average equilibrium surface temperature of our planet between 1.5°C and 4.5°C and that a doubling of atmospheric methane could increase the equilibrium surface temperature of the Earth between 0.2°C and 0.4°C. Similar calculations indicate that a doubling of atmospheric nitrous oxide could increase the equilibrium surface temperature between 0.3°C and 0.4°C and an increase of CFC-11 and CFC-12 to 2 ppbv each could increase the equilibrium surface temperature by about 0.3°C for each gas. A 50 percent increase of ozone in the troposphere could lead to an increase in surface temperature of about 0.3°C.

These calculations indicate that as a result of the increasing atmospheric levels of the greenhouse gases, the mean global temperature of our planet will increase by at least 1°C per decade.

Polar Warming and Rising Sea Levels

According to these theoretical calculations, a surface temperature increase of only 1°C or 2°C at midlatitudes could result in a heating of the polar regions several times greater. This would happen because the melting of polar ice and snow would expose the underlying land or ocean, which do not reflect the Sun's rays as well as highly reflective ice and snow. The greater absorption of solar radiation would amplify the temperature increase in these ice- and snow-covered regions.

Because heating results in both the thermal expansion of seawater and the melting of polar ice and snow, a temperature increase could result in a rise of the world's oceans by a foot or more by the year 2050. Such a rise in sea level would threaten the homes of tens of millions of people worldwide.

Further Information

This is a general presentation that can be used as a background to prepare units for all levels of students. If you need a more detailed description of the chemical reactions involved in ozone destruction, write to *Science Activities* for a photocopy of "The Chemistry of Ozone Destruction," an unpublished appendix to this article.

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PAPER

Atmospheric Chemistry: Causes and Effects

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ABSTRACT

Changes in the composition of the atmosphere may signal changes in our climate. Human activities are increasing the concentrations of gases with a warming potential contributing to the natural greenhouse effect. The measured loss of the ozone shield, particularly around the polar regions, is also caused by man's activities. While we are making progress in reducing the input of ozone depleting chemicals through an international agreement, the Montreal Protocol, we will see little effect on the atmosphere before the end of the century. Man's short-sighted activities cannot continue without resulting in environmental damage that could have implications far beyond those we have considered here.

INTRODUCTION

The first Earth Day took place, as you may remember, in April 1970. Both of my children and my wife were very interested in Earth Day, and as a laboratory scientist, I began to wonder if there were some way that I could react to this. Was there a way that I could use what I knew and apply it to some environmental problem?

A meeting later in 1970 on environmental applications of radioactivity led to an invitation to attend a Chemist-Meteorologist Workshop held in Fort Lauderdale, Florida, in January 1972 under the sponsorship of the Atomic Energy commission. There I heard the results of an interesting experiment that was being carried on by Jim Lovelock, a freelance scientist in England. Lovelock had invented a technique called electron-capture gas chromatography. Basically, this is a very sensitive technique for detecting certain molecules in extremely low concentrations, in particular, molecules that capture electrons, and these turn out to be mostly molecules that contain chlorine. Lovelock had set up the apparatus at his home in Western Ireland to see if he could measure any trace species in the Irish atmosphere.

When the wind blew from London he could see that there were several compounds present that he could detect. Moreover, when the wind blew from the Atlantic Ocean, he was still able to detect some compounds. Subsequently, he also took measurements from a ship bound for Antarctica and found that a compound called trichlorofluoromethane, also known as Chlorofluorocarbon-11, one of the inert gases used in spray cans, was present in every air sample he took. The chlorofluorocarbons (CFCs) are often identified by the trademarks of individual companies, especially the Dupont Company's "Freon."

I began to wonder what was going to happen to this man-made compound newly introduced into the atmosphere. When my research group gets a new graduate student or a new post-doctoral fellow, I discuss with them what sorts of research they are interested in pursuing. In 1973, a new post-doctoral fellow, Dr. Mario Molina, joined my group and chose as his project to explore what was happening to trichlorofluoromethane. Later, I will discuss the progress in this study over the past fifteen years. Before I get into the specifics of the destruction of the ozone layer by chlorofluorocarbons, I want to give a general description of the atmosphere and its radiative and chemical properties.

In addition to its major components (nitrogen, oxygen, argon), our atmosphere is naturally composed of water vapor, carbon dioxide, methane, nitrous oxide, ozone, and a number of other trace species as well as a number of non-natural components developed by man, for example, chlorofluorocarbons. Our primary source of energy is the sun. The sun is very hot (6000° K at the surface) and as a result emits radiation that is mostly in the wavelength region from 400 nanometers to 700 nanometers. We describe the radiation that comes from the sun into the atmosphere in terms of the response of the human eye. We talk about the visible wavelengths from red to violet. Beyond the red is the infrared and ultraviolet is on the far side of the violet. The wavelength of the individual radiation increases and the energy decreases as one moves from ultraviolet (short wavelength) to infrared (longer wavelength). Ultraviolet (UV) radiation can cause sunburn, while the much less energetic infrared (IR) radiation gives warmth (Figure 1).

While some solar radiation is reflected back into space by clouds, most of it is absorbed by the land, the oceans, or the atmosphere. An equivalent amount of energy must escape from the earth to maintain thermal balance, but because of the much lower temperature (300° K versus 6000° K for the sun), terrestrial radiation is emitted in the infrared. However, some of this IR radiation is absorbed by water vapor, carbon dioxide, ozone, and CFCs in the atmosphere. The earth warms up because of this trapping of IR radiation by atmospheric gases, and this natural process has been termed the greenhouse effect (Figure 2). However, an increase in any of the absorbing gases increases the amount of heat from the earth that is prevented from escaping to space. The earth must then warm up still more to push IR radiation out at those wavelengths *not* absorbed by these gases. If the earth did not have a greenhouse effect then it would be approximately 33 degrees centigrade cooler than it is and not be conducive to life as we know it; for example, all water would be frozen. At the other extreme is Venus where the atmosphere has a much higher carbon dioxide content and retains much more of the radiant heat and where the resulting surface temperature is about 700° K.

In our atmosphere, one molecule of CCl_2F_2 (the chemical description of CFC-12 before switching to the technological term) is 10,000 times more effective at trapping heat than one additional molecule of carbon dioxide. Carbon dioxide is increasing at a rate of about 1,500 parts per billion by volume (ppbv) yearly (versus 0.02 ppbv for CFC-12) and still accounts for half or more of the incremental greenhouse increase. The larger heat trapping ability of CFCs is important to remember because CFCs also play a very important role in the reduction of the ozone layer. Both of these impacts are significant, especially when discussing the establishment of domestic and international laws and policies to reduce global warming and destruction of the ozone layer.

One other important point can be made about scientific measurements and greenhouse gases. The longest running data set related to greenhouse gases and potential global warming is that of carbon dioxide taken by David Keeling (Scripps Institution of Oceanography, University of California at San Diego) at the Mauna Loa Observatory in Hawaii (see Kellogg's Figure 1 in this issue). The familiar saw-toothed graph clearly shows a substantial increase in carbon dioxide measurements in the atmosphere from the beginning of the record in 1958 (315 ppm) to the present (355 ppm). The saw-toothed pattern is reflective of the growth in flora that occurs in the spring and summer in the Northern Hemisphere where the leaves act as a carbon sink. When the leaves fall in the winter, the trees and other plants no longer act to take up and store additional carbon dioxide and allow the atmospheric levels of CO_2 to rise again. The Mauna Loa record was a crucial piece in the identification of changes in the atmospheric concentration of greenhouse gases. That graph is now nearly synonymous with the concept of global change.

FIGURE 1. Solar radiation upon the earth's atmosphere. Visible radiation (400 to 700 nm) penetrates to the surface as does energetic ultraviolet radiation with wavelengths between 320 to 400 nm. Very high energy ultraviolet radiation is absorbed by (*a*) molecular O_2 to create the ozone layer in the stratosphere; and (*b*) ozone to create the stratosphere itself. Little infrared radiation is given off by the sun, but all of the earth radiation falls in the long wavelength infrared region.

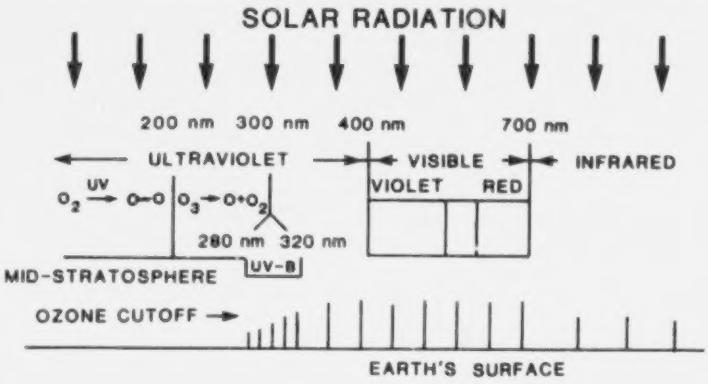
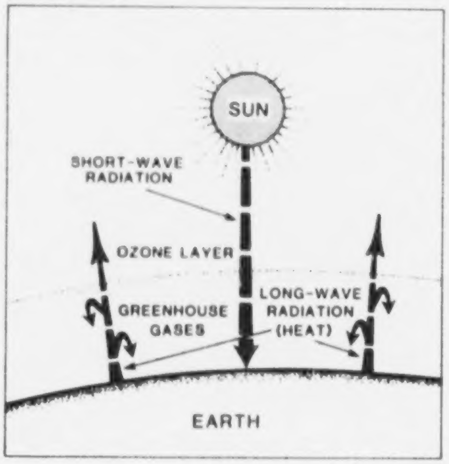


FIGURE 2. The greenhouse effect. Visible radiation from the sun reaches the earth's surface unhindered, but the outgoing long-wave radiation is partially trapped, or retained, by carbon dioxide and other gases in the atmosphere.



CFC CHEMISTRY AND OZONE DEPLETION

Trichlorofluoromethane is transparent, insoluble in water, and relatively unreactive. Nothing happens to it on the time scale of a year or so. But what can happen to it if it is left long enough?

Red light penetrates through the atmosphere better than blue light. The light near sunset is coming through a very long atmospheric path, and the blue light is scattered out, leaving a very red sun. Because the blue wavelengths from the sun are scattered by the atmosphere, the sky appears blue. These effects remind us that radiation of different wavelengths has quite varying effects in the atmosphere.

Infrared radiation does not carry enough energy to cause most molecules to decompose. Violet or ultraviolet radiation from the sun has enough energy to cause some of the trichlorofluoromethane molecules to decompose but only if this UV reaches the CFC molecule.

Most (98 percent) of the energy from the sun arrives in the visible wavelength with 2 percent in the ultraviolet. However, this ultraviolet radiation makes important changes in the gases in the atmosphere. Ultraviolet radiation can split molecular oxygen (O_2) into two oxygen atoms. The usual fate of an oxygen atom is to find another molecule of oxygen and form triatomic oxygen, or "ozone." It is, therefore, molecular oxygen in the presence of ultraviolet radiation from the sun that creates ozone (Figure 3). As soon as there is ozone, there is another molecule that can absorb ultraviolet radiation, splitting it into an oxygen atom and an O_2 or oxygen molecule. This newly-released atom of oxygen usually finds another O_2 and reforms the ozone.

Ultraviolet radiation is always making ozone and it is also decomposing ozone, and in the process the UV energy is converted into heat. This heat source creates the stratosphere (Figure 3), a region in which the temperature increases as altitude increases. Thus, the ozone "layer" produces the stratosphere and, at the same time, prevents much of the ultraviolet radiation from the sun from reaching the surface of the earth.

Molina and I developed the theory that if a molecule of trichlorofluoromethane was released in the lower atmosphere (the troposphere, where it gets colder with altitude and where we live and breathe) and it could get high enough (into the stratosphere), it could absorb ultraviolet light. Trichlorofluoromethane would then absorb solar UV radiation in the stratosphere and be split apart to produce free chlorine atoms. The stratosphere, then, because of the high energy ultraviolet radiation from the sun, would have the ability of converting this CFC molecule to chlorine atoms. So, what is going to happen to the chlorine atoms?

That question turns an interesting scientific problem into an environmental issue. A chlorine atom (Cl) reacts with the ozone (O_3) to give off a species called chlorine oxide (ClO). Chlorine oxide then reacts with oxygen atoms (O) to yield atomic chlorine again. The overall result of this sequence of two reactions is that an ozone molecule (O_3) and an oxygen atom (O) (which otherwise would have formed an ozone [O_3]) have been converted back to molecular oxygen (O_2). The chlorine atom is still there, ready to repeat this process (Figure 4).

This is a chain reaction. It is catalytic because the chlorine causes the ozone to be converted to oxygen, but the chlorine is not used up in the process. In fact, the two reactions require only one minute in the stratosphere. A chlorine atom is on the loose, destroying ozone at the rate of one molecule per minute. The chlorine atoms eventually make their way back through the ozone layer toward ultimate deposition in rainfall as hydrochloric acid (HCl). The roundtrip for the chlorine atom from release in the stratosphere to final rainout requires a year or two, during which time each chlorine atom destroys approximately 100,000 molecules of ozone. When man is emitting nearly one million tons of CFCs on a yearly basis, that translates into an ozone loss about 10^5 times larger.

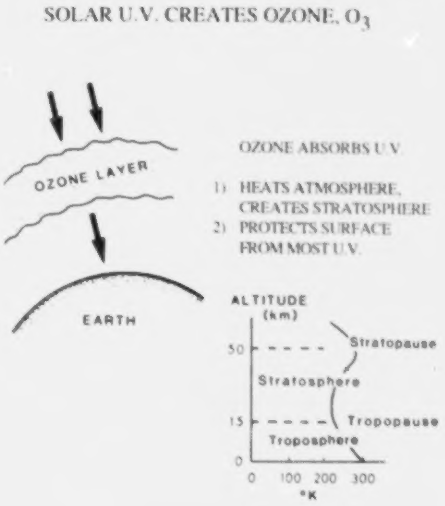


FIGURE 3. Schematic diagram for absorption of solar ultraviolet radiation by ozone with the creation of the stratosphere (temperature increase with increasing altitude).

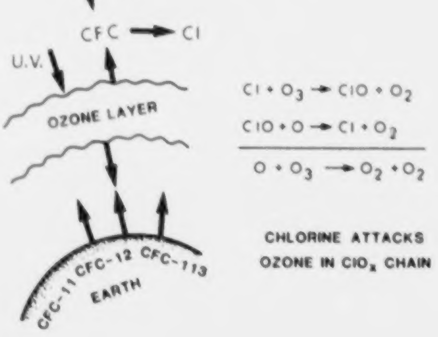


FIGURE 4. Schematic diagram for release of CFC gases at the surface, their photolysis above the ozone layer, and the chlorine chain reaction for removal of ozone.

U.V.
CFC → Cl
U.V.
OZONE LAYER
CFC-11
CFC-12
CFC-113
EARTH
$Cl + O_3 \rightarrow ClO + O_2$
$ClO + O \rightarrow Cl + O_2$
$O + O_3 \rightarrow O_2 + O_2$
CHLORINE ATTACKS OZONE IN ClO_x CHAIN

BEST COPY AVAILABLE

At the time Molina and I first made our calculations and predictions, no measurements existed anywhere in the stratosphere for any chlorine containing compound. However, we had calculated the CFC concentrations to be expected at each altitude, based on laboratory studies and a simple one-dimensional atmospheric model. Through the lower atmosphere, the troposphere, we anticipated no change in the relative amounts of trichlorofluoromethane and nitrogen and oxygen. However, in the stratosphere, CFC-11 should photodissociate, decreasing in mixing ratio from 20 to 30 km and with almost none left at 35 km.

Using a technique originally devised in the nineteenth century by chemist Gay-Lussac, air samples were collected, brought back to the laboratory for measurement, and the results were compared with the predictions. The chlorofluorocarbons do get into the stratosphere, and once they are there, they disappear essentially as predicted; that is, the solar ultraviolet will break down the CFCs and begin the process of ozone destruction. As soon as it was confirmed that the CFCs do indeed reach the stratosphere and that they photodissociate, we returned to the question of potential atmospheric sinks. Do the CFCs really not react in the lower atmosphere? Careful comparison of the amounts of CFCs emitted to the atmosphere versus the amounts still remaining there confirmed that the atmospheric lifetimes were indeed very long—a century or so. No rapid tropospheric removal processes exist for these compounds. The only removal process that seems to work is ultraviolet radiation in the middle stratosphere, above the ozone layer.

Lovelock's CFC-11 measurements in 1971 showed approximately 70 parts per trillion. In the summer of 1979, we found approximately 170 parts per trillion of CFC-11 in the Northern Hemisphere, an increase by more than a factor of 2 in just eight years! From continuations of such measurements, we now know that five times as much chlorine is now in the atmosphere as there was in 1950. Most of that increase has happened since 1970, and most of it represents carbontetrachloride, methylchloroform, and the three most common chlorofluorocarbons. The atmosphere has indeed changed very rapidly as far as chlorine is concerned.

THE ANTARCTIC AND ARCTIC OZONE HOLES

The most striking change in the atmosphere in the last decade or so was found from measurements made by the British Antarctic Survey at its Halley Bay Station on the Antarctic coast. They have operated an ozone measuring instrument since 1957. All through the 1960s, ozone measurements (averaged for October—the Antarctic spring) ranged from 300 to 320 parts per billion. Then suddenly in the late 1970s, the ozone amounts began to fall off, dropping below 200 by October 1984 (Figure 5). Something drastic had happened over Antarctica. The amount of ozone there in October is now much less than twenty years ago. Some air masses at altitudes around 15 km have now been measured that show no ozone at all!

The Northern Hemisphere has lost some ozone as well (Figure 6). It is especially noticeable in the winter. There is about 6 percent less ozone in the higher latitudes of the Northern Hemisphere in winter now than in 1970. There is a loss of about 4.7 percent over the northern part of the United States and some loss in the southern part of the United States. The yearlong average change in ozone in the north temperate zone has already reached 2 or 3 percent.

We now recognize that we are losing ozone not just over the Antarctic but also over the Northern Hemisphere as well. Furthermore, extensive experiments in the polar regions have thoroughly established that the loss of ozone has been caused by chlorine chemistry, with most of the chlorine arising from decomposed CFC molecules. Subsequent expeditions have shown that the atmospheric chemistry causing the loss of the ozone in the Arctic is very similar to what occurs in the Antarctic. The circulation of the air, though, is different in the two regions.

In the Antarctic, the stratospheric air stays in the polar vortex and goes around and

FIGURE 5. Average ozone concentrations above Halley Bay, Antarctica, for the month of October, showing the sharp decline since the mid-1970s. Data of J. Farman and colleagues from the British Antarctic Survey.

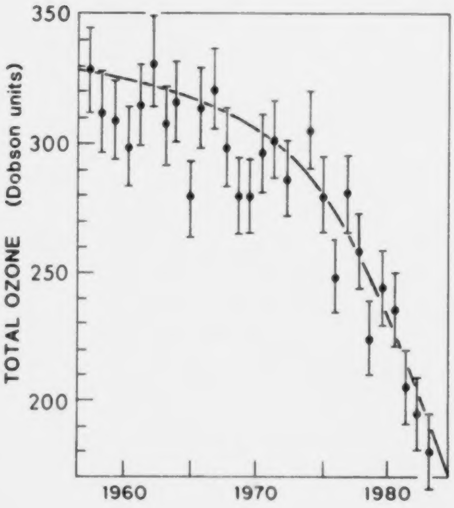
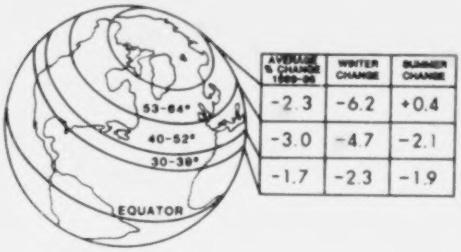


FIGURE 6. Average ozone changes for latitude bands in the Northern Hemisphere during the seventeen-year period, 1969 to 1986.



around all winter long, becoming very cold, cold enough to allow the formation of polar stratospheric clouds. These clouds trigger some special chemistry that makes the vortex and its ozone very vulnerable to the arrival of sunlight after the long polar winter. As spring arrives, major ozone losses occur within the vortex during the next several weeks. In the Northern Hemisphere, the polar vortex is not as strong and one air mass after another enters the polar darkness and soon emerges back into low sunshine. We lose a little bit of ozone from each parcel of air instead of a lot of ozone from one parcel of air. But the consequence is that we are losing ozone in both hemispheres, although more of it in the Southern Hemisphere.

OZONE LOSS: SO WHAT?

So what difference will a reduction in the ozone layer make? If less ozone exists in the upper stratosphere, less heat will be produced there because not as much UV energy will be absorbed and that will mean a change in the temperature profile because there would not be as much heat in the stratosphere. The wind patterns may also be altered because they depend on temperature gradients in the atmosphere in various regions. In effect, we could be changing the climate. With less ozone, too, more ultraviolet radiation will arrive at the surface of the earth, especially the ultraviolet B, which is known to cause biological damage in humans and other living organisms (Figure 7).

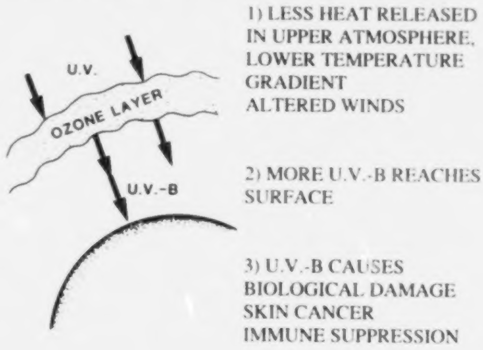
About half to two-thirds of the biological species tested turn out to be sensitive to ultraviolet B. Among the effects are stunted growth in many species of plant. The only species for which we have really good data is the human species, and we know that UV-B causes human skin cancer and cataract development. In the United States about 500,000 people a year develop skin cancer for the first time. Malignant melanoma is the most serious form of skin cancer, fatal in about 20 percent of the cases. Most forms of skin cancer are not fatal if treated but are often disfiguring.

POLITICAL RESPONSE

From the time of our initial discovery, Molina and I felt that this reduction in the ozone layer was too dangerous to continue and called for a ban on further emissions of CFCs to the atmosphere. The dollar value of chlorofluorocarbons that were going into the atmosphere in 1974 was $2 billion per year, and the value of the products using them were much larger. However, the chemical industry did not immediately leap at our suggestion that they should stop manufacturing and using chlorofluorocarbons.

The early days of our work and our early publications generated a great deal of political discussion. At that time, chlorofluorocarbons in the United States were primarily used as propellant gases for aerosol sprays (which accounted for about two-thirds of the total use). As a result of the scientific work and the political concern, the United States announced in 1976 that it would ban the use of chlorofluorocarbons as propellants in aerosol sprays. Canada, Norway, and Sweden followed this lead, and many felt that the CFC-ozone problem had been solved.

FIGURE 7. Schematic diagram for effects resulting from loss of ozone in stratosphere.


U.V.
OZONE LAYER
U.V.-B
1) LESS HEAT RELEASED IN UPPER ATMOSPHERE, LOWER TEMPERATURE GRADIENT
ALTERED WINDS
2) MORE U.V.-B REACHES SURFACE
3) U.V.-B CAUSES BIOLOGICAL DAMAGE
SKIN CANCER
IMMUNE SUPPRESSION

But, in fact, there are many other uses of CFCs. The refrigerant in your home refrigerator and in automobile air conditioners is CFC-12. Polyurethane foam is made with chlorofluorocarbons. Nearly every piece of electronic apparatus in use has been cleaned with CFC-113 or with methyl chloroform, another chlorine-containing gas. As a result of growing use in products other than aerosols, the yearly release of CFCs has remained roughly constant for the last fifteen years. With a constant release rate and long atmospheric lifetimes, the total amount of chlorine in the atmosphere has steadily increased.

INTERNATIONAL ACTIVITY

The destruction of the ozone layer is an international problem, and the United States is not the only producer and user of CFCs. A United Nations Environment Programme to protect the ozone layer was signed in Vienna in 1985, and a protocol outlining proposed protective actions followed in Montreal in September 1987. The Montreal Protocol originally specified a 20 percent reduction in the release of fully halogenated chlorofluorocarbons by 1994 and a further 30 percent reduction in 1999. Even if the Montreal Protocol were fully implemented, the reductions would have only a minor effect on the amount of chlorine in the atmosphere before the end of the century. The provisions over the next ten years for production and use of CFCs by developing countries are part of the reason. The other element is the fact that CFCs are long-lived in the environment. However, with the observation of massive ozone loss over the Antarctic coupled with the knowledge that it was definitely caused by manmade chlorine, the Montreal Protocol was reevaluated in June 1990 and called for a complete phase out of CFC emissions.

The question of where we go in the next few decades depends on whether we follow the Montreal Protocol closely or whether we are negligent in its implementation and allow the levels of CFC emissions to continue to rise. There is no way that we are ever going to return, in our lifetime, to chlorine concentrations that were in the atmosphere as recently as the 1960s. We are going to live with ozone depletion. We do not know exactly what that is going to mean because there are time delays involved in reduced emissions and reduced atmospheric levels. At present there is a ten-year time delay while we are phasing out and then probably another ten-year delay for leakage from all of the refrigerators and air conditioners that we are using now. Then there are another few years until the CFCs work their way into the stratosphere. Following this pattern, the worst of the ozone reduction will occur about the year 2010 or 2015. We are twenty or twenty-five years away from that maximum.

POSSIBLE SUBSTITUTES

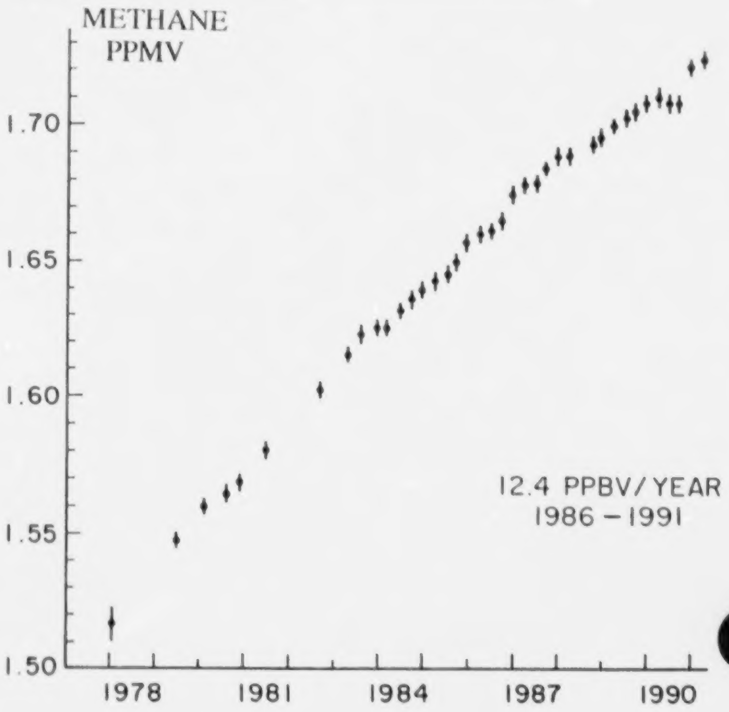
Much of our ability to reduce the use and manufacture of CFCs will depend greatly on developing reasonable substitutes. The apparent willingness and ability of industry to prepare substitutes and go along with an Environmental Protection Agency call for a total or nearly total phase-out of CFCs represents a tremendous policy shift in the United States over the past fifteen years.

I would like to make a note about possible substitutes. There is a sharp distinction in atmospheric behavior between chlorofluorocarbons that have no hydrogens (CFCs) and their hydrogen-containing analogs (HCFC). Those with hydrogen can be broken down in the troposphere and removed before they reach the stratosphere. The threat to stratospheric ozone then is greatly reduced. We need to keep in mind, though, that we live and breathe the troposphere and that the addition of any new breakdown products here should be looked at very carefully.

CLOSING COMMENTS

Dr. Keeling has recorded the increasing levels of carbon dioxide in the atmosphere; we and others have studied the increasing levels of methane in the atmosphere (Figure 8) and the increasing levels of chlorofluorocarbons in the atmosphere. All of those increasing levels of chemicals in the atmosphere are the result of activities of mankind. The driving force for the activities of mankind that result in increased emissions of CO_2, CH_4, or CFCs, over the last

FIGURE 8. Global average atmosphere methane concentrations since 1978 (D. Blake and F.S. Rowland).



couple of centuries, has been the improvement of our standard of living. Traditionally, the way we have improved our standard of living has been to use more energy and more materials and to release the waste products into the atmosphere, land, or oceans. Rapidly increasing population growth coupled with the demand for a higher standard of living is the underlying problem. If we continue to act as we have, we will continue to see a rapid change in the atmosphere. The question presumably requires consideration of population control, conservation and better use of our limited resources, and inclusion of the real costs of emission of our waste products as we increase our standard of living. It is not too soon to consider these very serious issues. While we are beginning to understand the science, we must also begin to understand and change human behavior.

ADDITIONAL READING

Blake, D.R. and Rowland, F.S. 1988. Continuing worldwide increase in tropospheric methane, 1978 to 1987. *Science* 239:1129–31.

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Molina, L.T. and Molina, M.J. 1987. Production of Cl_2O_2 from the self-reaction of the ClO radical. *J. Phys. Chem.* 91:433–36.

Rowland, F.S. 1974. Aerosol sprays and the ozone shield. *New Scientist* 64:717–20.

Rowland, F.S. and Molina, M.J. 1975. Chlorofluoromethanes in the environment. *Rev. Geophys. Space Phys.* 13:1–35.

WMO-NASA. 1986. *Atmospheric Ozone 1985*. 3 vols. WMO Global Ozone Research and Monitoring Project, rep. no. 16.

Monitoring Ozone from Your Classroom

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> *The machine does not isolate man*
> *from the great problems of nature*
> *but plunges him more deeply into them.*
> *—Antoine de Saint Exupery*[*]

Section I
When Does the Ozone Hole Appear?

Goal

To determine the time of year that the ozone hole is most apparent, by using actual data.

Key Concepts

- The ozone hole is only apparent during certain months.
- Although the term ozone "hole" is widely used in popular and scientific literature, the phenomenon is more correctly described as a low concentration of ozone.

Overview

Students construct a graph using raw data obtained from orbiting satellites to determine the time of year that the ozone hole is most apparent. Students also gain experience with managing a large amount of data.

Materials

- Data table: Ozone Concentration For Latitudes 90°S to 30°S, 1987 (pages 61-62)
- Graph paper

Procedure

Referring to the data in the Ozone Concentration data table:

a. Determine scale for each axis; plot OZONE CONCENTRATION (Dobson Units/DU) on the vertical axis and TIME (days) along the horizontal axis.

b. Using these data and the graph paper, construct a graph showing the relationship between ozone concentration and day of the year.

c. Label the months on your graph, correlating numbers with dates.

NOTE: *There are a lot of data here. You may want to treat them in one of the following ways: (1) plot only every tenth day, (2) average*

---

[*] *Wind, Sand And Stars*

BEST COPY AVAILABLE

every 10 days' worth of data and plot this average value, (3) plot a small portion of data, then combine your efforts with classmates' work to produce one large graph. Be sure to use a constant scale.

TO THE STUDENT

Observe

1. When is the ozone concentration lowest? Give month and season.
2. When is the ozone concentration highest? Give month and season.

Interpret

3. Do you need to plot each day's Dobson Units? Explain.
4. How is the ozone level related to the time of year?
5. Which is the best description of a low number of Dobson Units?
   a. An area of no ozone
   b. An area of low concentration of ozone molecules
   c. An area of high concentration of ozone molecules
6. Would you describe this phenomenon as a "hole"? Why or why not?

Apply

7. Why do you think the ozone level begins to decrease when it does?
8. What is the value of using an entire class to analyze these data?

Section II

Have Antarctic Ozone Levels Changed In Ten Years?

Goal

Students will generate and interpret false color plots of ozone depletion in Antarctica over a ten year-period.

Key Concepts

- Ozone concentrations over Antarctica have changed in the last ten years.
- Using color to represent data simplifies data interpretation.

Overview

Ozone plots published in newspapers and magazines may be familiar to you, but do you understand them? In this activity students generate and interpret such plots to gain a better understanding of ozone depletion in Antarctica. This exercise models current science by using color codes to facilitate data interpretation.

Materials

- Ozone plots: Total Ozone Monthly Mean, October 1980-1989 (pages 65-69)
- Ozone plot: Antarctica: South Polar Plot (page 63)
- Colored pencils - 16 different colors

Preparation

Line drawings may be enlarged on a copying machine—enlarging 150 percent will put one plot horizontally on a standard page. The line drawing, Antarctica: South Polar Plot, can be made into a transparency and superimposed over plots to provide geographical information. Divide your class and generate a few series of plots to save time.

***Note:** Each series may have a different color key but the color key must be the same within a series.*

Procedure

Working in student groups:

a. Determine color values for the Dobson Unit ranges. (Technicians utilize computers to assign specific colors to specific ranges of Dobson Units. For example, values 100-124 may be yellow; 125-149 may be orange, and so on.)
b. Color the key on each of the ten plots, using your chosen colors.
c. Color each plot, using your color key to guide you.
   ***Note:** Some plots may show only a few of the colors from their keys.*

TO THE STUDENT

Observe

1. List the value and year for the lowest ozone concentration in these data.
2. Describe the geographic location of the ozone hole.

Interpret

3. Describe the general trend of ozone values from 1980 to 1989.
4. Does the ozone always drop from year to year?
5. Why are ten years of data better than two?

Apply

6. Should we make hundred-year predictions using ten years of data? Discuss.
7. How would a plot for a specific day differ from a monthly mean plot? Why interpret monthly mean plots versus daily plots?
8. Collect pictures of ozone plots from magazines and newspapers. Compare these plots with ones you generated in this experiment.
9. If your class produced more than one series of plots with different color keys, compare these keys. Which are the easiest to understand? Which do the best job of depicting the data?

Glossary

Austral—Southern, or having to do with the southern hemisphere.

Chlorofluorocarbon (CFC)—A compound containing carbon, chlorine and fluorine atoms; an example is Freon™, used in air conditioners and refrigerators.

Dobson Unit—A measurement of the thickness of the ozone layer, by an equivalent layer of pure ozone gas at normal temperature and pressure at sea level. In other words, 100 DU = 1 mm of pure ozone gas at normal temperature and pressure at sea level.

Ozone—A form of oxygen produced by energy from ultraviolet radiation or electricity such as lightning. When present in the air in higher concentrations than normal, it can be detected by its sharp pungent odor, which resembles weak chlorine.

Polar Night—The period of total darkness during the winter months that occurs at both of Earth's polar regions.

Ultraviolet Rays—The invisible rays in the part of the spectrum beyond violet. The wavelength of ultraviolet rays is shorter than those of visible violet and longer than those of x-rays.

Topics for Further Research

- *Nimbus-7* satellite
- SSBUV (Shuttle Solar Backscatter Ultraviolet) instrument
- Chlorofluorocarbon

More Ideas:

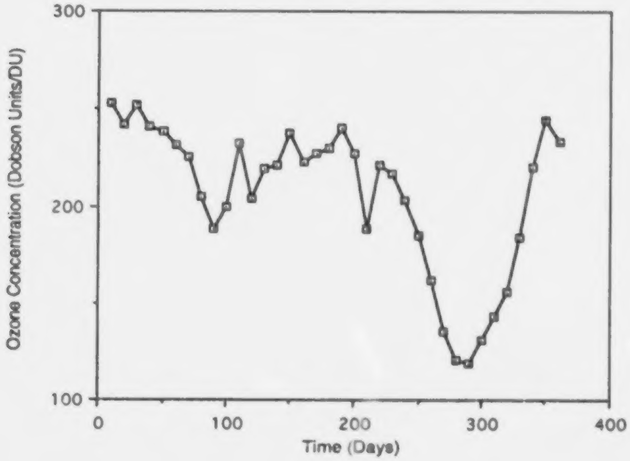
- Color code and interpret the seasonal plots provided (January, April, July, October 1987).
- Research ozone changes according to latitude.
- Research ozone measuring techniques prior to 1980.
- Compare Arctic and Antarctic ozone levels.
- Update these experiments by researching current ozone values.

TO THE TEACHER

Section I: According to these data, the ozone reaches its lowest values in October, which is spring in the Southern Hemisphere. The highest concentrations of ozone occur over Antarctica in January, mid-austral summer.

Student graphs should look something like the one below.

OZONE CONCENTRATION FOR LATITUDES 90'S to 30'S, 1987



Sometimes too much data confuse rather than clarify an issue. This activity focuses on trends, thus it is not necessary to plot each day's Dobson Units. The ozone levels are fairly consistent throughout the year, with a noticeable drop in September and October. Low

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readings of ozone mean there are fewer ozone molecules in that particular area. The ozone hole is more aptly described as a low concentration, since to date there have been no recorded readings of zero for ozone.

Ozone concentration is lowest in the spring, following the cold winter. Scientific studies link ozone level to atmospheric temperature. Students can benefit from each others' work, accomplishing more as a class than they could individually. Before scientists had wide access to super-computers, they often employed rooms full of people using calculators to manage large amounts of data.

Section II: The measurements for 1987 and 1989 are equally low at 125 DU. The greatest ozone depression is primarily over the Antarctic continent. Using ten years of data, the general downward trend of ozone levels is quite obvious, but would not be clear with only two years of data (note: 1987 and 1988).

We have not been collecting satellite data long enough to yield statistically accurate, long-term predictions, and must, therefore, incorporate data from ground-based ozone-monitoring equipment as well. More data are usually preferred and generally yield better (more reliable) results than less data. Data sets, both small and large, must be subjected to sophisticated statistical analysis to test their reliability. Daily plots are more complex and show far more detail. Monthly average plots are easier to interpret because the plots are simpler, without the extremes. Collected ozone plots should look similar to the ones your class generates. The color keys will differ since these are nonstandard and dependent upon individual scientists. Color keys are often based on the visible spectrum, or rainbow, and range from light to dark for high to low values. You will note larger differences if you collect a daily plot, which will look far more complex for reasons described previously. (Color keys are a matter of personal preference, though some communicate better than others.) Students should be able to support their conclusions.

What's the Science? The large, rapid, and unexpected decrease in the amount of springtime Antarctic ozone over the last decade cannot be attributed to known natural processes. Although there is increasing evidence that present-day pollution plays a major role in this, scientists do not, at this time, have a model that adequately simulates the chemistry or weather conditions that accompany ozone depletion. The following paragraphs outline our current understanding of ozone chemistry.

As sunlight strikes the upper atmosphere, oxygen molecules react to form ozone.[*] The resulting ozone concentration is rather small but it has a very important effect. The ozone gas absorbs much of the Sun's ultraviolet radiation,[**] which would harm life on Earth in excessive amounts. As ozone absorbs ultraviolet light energy, the temperature of the surrounding air increases. This warmer air does not mix with the cooler air beneath it, confining the majority of the ozone gas to the stratosphere (approximate altitude 25 km or 15 mi).

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[*] A molecule of ozone consists of three atoms of oxygen bonded together.

[**] A component of sunlight

Ozone may remain in the atmosphere or decompose back to oxygen. Two things seem to speed up the natural process of ozone destruction: (1) the presence of pollutants such as oxides of nitrogen and chlorofluorocarbons (CFCs) which catalyze[*] the reaction, and (2) the presence of polar stratospheric clouds, which provide aerosol surfaces needed for the catalyzed reaction. Also, certain weather conditions, such as sunlight and extremely cold temperatures, are necessary for the accelerated ozone loss. Winds, high in the atmosphere above the South Pole, create a stable vortex[**] that concentrates the cold, and thus the ozone destruction. The resulting severe depletion of ozone is localized above Antarctica and is generally referred to as the ozone hole.

The ozone hole appears in the austral spring, following the continent's coldest season and polar night. Ozone depletion over the Arctic is not as well defined as in Antarctica. The relatively warmer northern climate, different distribution of landmasses, and lack of a stable windy vortex are thought to be reasons for this.

The ozone hole cannot be seen by the human eye, but must be measured by special instruments. Since 1978, the Total Ozone Mapping Spectrometer (TOMS), an instrument aboard the *Nimbus-7* satellite, has been observing ozone levels by measuring ultraviolet radiation that is backscattered by the atmosphere or reflected from Earth's surface.

TOMS measures the total ozone from the ground to an altitude of 50 km. Each section of the flat ozone plots, generated in this activity, represents a column of atmosphere thousands of meters thick. TOMS meas- ures ozone values from above for the entire depth of the atmosphere. Since this type of ozone mapping requires sunlight, measurements cannot be made at night or in polar areas during their season of 24-hour darkness (polar night). Although TOMS collects ozone data for the entire planet, the data in these lab exercises are only from the Southern Hemisphere. The Shuttle Solar Backscatter Ultraviolet instrument, flown on various Shuttle missions, including STS-34, assists scientists in calibrating TOMS. Ozone levels are recorded in Dobson Units, a measurement of the thickness of ozone layer, by an equivalent layer of pure ozone gas at normal temperature and pressure at sea level. In other words, 100 DU = 1 mm of pure ozone gas at normal temperature and pressure at sea level. The average amount of ozone at mid latitude is 3 mm or 300 DU.

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[*] In this instance, the reaction is speeded up.

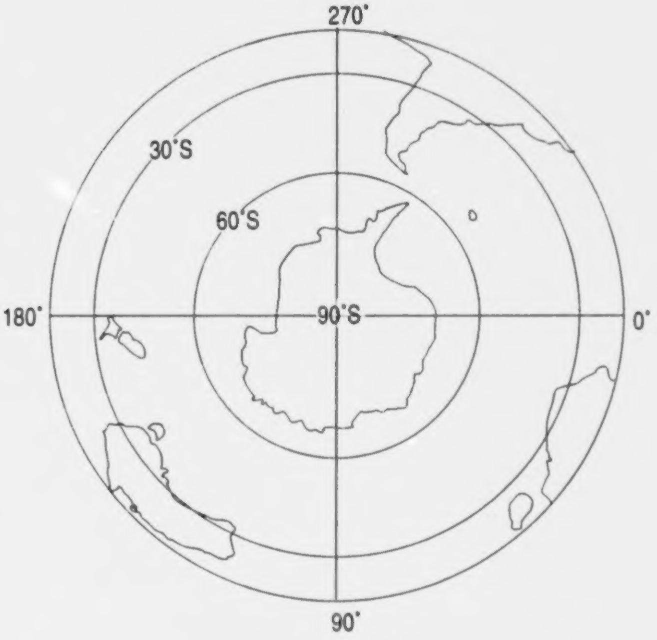
[**] A whirlpool of wind.

Ozone Concentration for Latitudes 90°S to 30°S, 1987

DAY	DU	DAY	DU	DAY	DU	DAY	DU
1	255	47	242	93	200	139	219
2	254	48	238	94	201	140	221
3	254	49	238	95	197	141	227
4	248	50	238	96	199	142	218
5	251	51	226	97	205	143	217
6	253	52	228	98	201	144	225
7	254	53	234	99	206	145	217
8	251	54	240	100	200	146	216
9	251	55	242	101	205	147	218
10	253	56	239	102	208	148	228
11	257	57	239	103	210	149	227
12	255	58	240	104	222	150	237
13	255	59	236	105	227	151	226
14	253	60	231	106	224	152	223
15	254	61	237	107	218	153	203
16	253	62	238	108	222	154	222
17	252	63	244	109	225	155	207
18	251	64	236	110	232	156	206
19	245	65	222	111	235	157	212
20	242	66	224	112	231	158	229
21	251	67	227	113	229	159	234
22	246	68	220	114	232	160	223
23	251	69	219	115	216	161	233
24	251	70	225	116	213	162	219
25	249	71	219	117	208	163	215
26	246	72	208	118	219	164	231
27	250	73	213	119	227	165	235
28	249	74	210	120	204	166	233
29	247	75	217	121	215	167	222
30	252	76	217	122	210	168	228
31	246	77	217	123	212	169	216
32	250	78	210	124	213	170	227
33	250	79	203	125	213	171	229
34	249	80	205	126	216	172	209
35	249	81	206	127	233	173	203
36	248	82	208	128	235	174	220
37	246	83	201	129	229	175	220
38	243	84	198	130	219	176	229
39	243	85	203	131	226	177	233
40	241	86	207	132	228	178	231
41	244	87	204	133	220	179	237
42	244	88	203	134	213	180	230
43	240	89	188	135	211	181	235
44	243	90	188	136	228	182	230
45	244	91	195	137	227	183	221
46	233	92	193	138	230	184	217

Ozone Concentration for Latitudes 90 °S to 30 °S, 1987 *(cont.)*

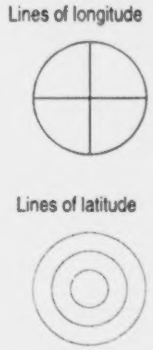
DAY	DU	DAY	DU	DAY	DU	DAY	DU
185	225	231	201	277	112	323	167
186	232	232	217	278	106	324	165
187	228	233	210	279	112	325	160
188	227	234	219	280	121	326	157
189	228	235	218	281	119	327	164
190	240	236	212	282	117	328	170
191	234	237	203	283	127	329	174
192	238	238	207	284	132	330	184
193	233	239	193	285	127	331	181
194	233	240	203	286	125	332	184
195	209	241	206	287	125	333	191
196	207	242	210	288	122	334	197
197	223	243	209	289	121	335	200
198	215	244	194	290	119	336	209
199	229	245	202	291	124	337	202
200	227	246	189	292	122	338	210
201	235	247	204	293	125	339	219
202	230	248	173	294	125	340	220
203	205	249	173	295	120	341	215
204	204	250	185	296	124	342	227
205	234	251	173	297	129	343	228
206	229	252	175	298	128	344	231
207	244	253	178	299	133	345	246
208	225	254	171	300	131	346	249
209	208	255	161	301	135	347	248
210	188	256	158	302	133	348	252
211	172	257	166	303	133	349	247
212	214	258	160	304	135	350	244
213	201	259	161	305	141	351	245
214	208	260	162	306	143	352	242
215	208	261	164	307	142	353	242
216	215	262	164	308	141	354	250
217	207	263	151	309	141	355	249
218	190	264	147	310	143	356	249
219	204	265	144	311	142	357	247
220	221	266	149	312	143	358	240
221	220	267	151	313	143	359	231
222	228	268	146	314	147	360	233
223	224	269	144	315	141	361	236
224	220	270	135	316	146	362	244
225	200	271	131	317	146	363	242
226	230	272	122	318	153	364	242
227	199	273	112	319	154	365	243
228	183	274	111	320	156		
229	172	275	119	321	155		
230	217	276	124	322	163		



ANTARCTICA

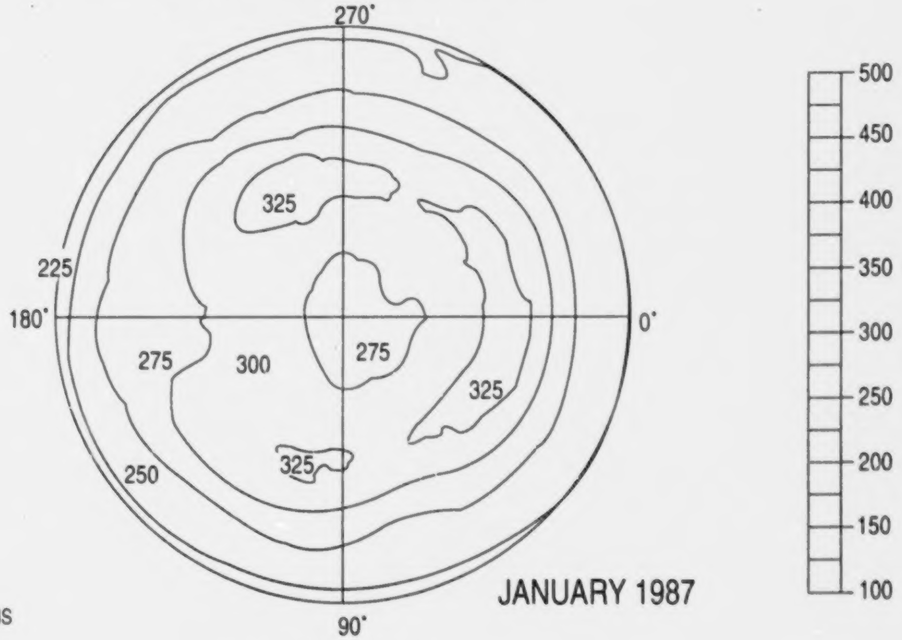
270°
30°S
60°S
180°
90°S
0°
90°

South Polar Plot



Lines of longitude
Lines of latitude

NOTE: latitude of outer circle is approximately 10°S.



TOTAL OZONE MONTHLY MEAN

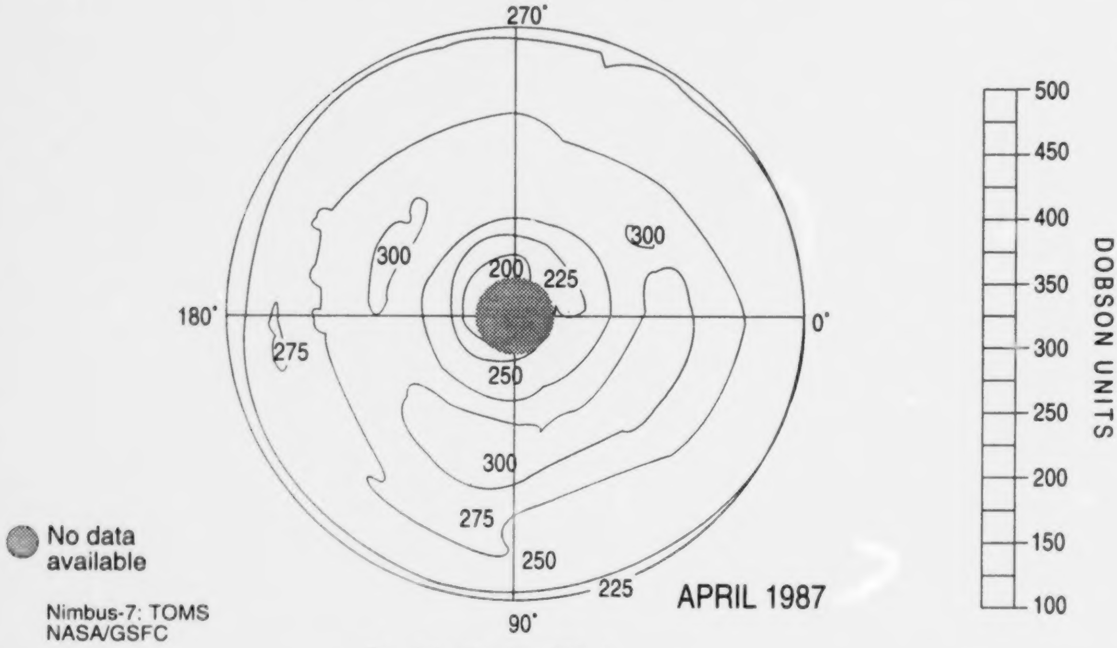
270°
325
225
180°
0°
275
300
275
325
250
325
90°
500
450
400
350
300
250
200
150
100
DOBSON UNITS

JANUARY 1987

Nimbus-7: TOMS
NASA/GSFC

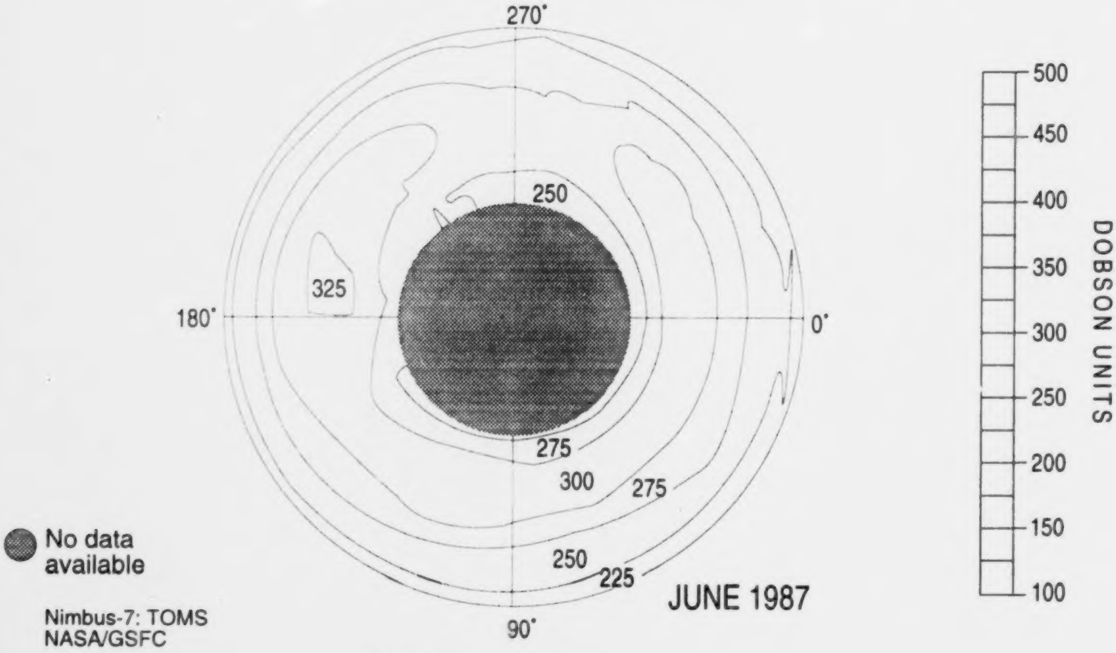
South Polar Plot

TOTAL OZONE MONTHLY MEAN


270°
180°
0°
90°
200
225
250
275
300
300
300
275
250
225
APRIL 1987
500
450
400
350
300
250
200
150
100
DOBSON UNITS
● No data available
Nimbus-7: TOMS
NASA/GSFC

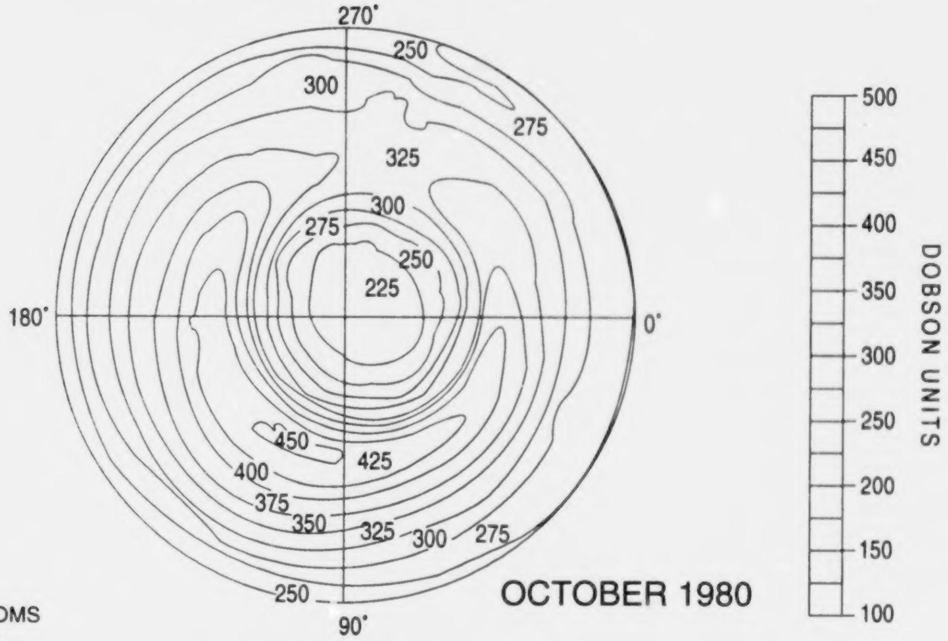
South Polar Plot

TOTAL OZONE MONTHLY MEAN


270°
180°
0°
90°
250
325
275
300
275
250
225
JUNE 1987
500
450
400
350
300
250
200
150
100
DOBSON UNITS
● No data available
Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

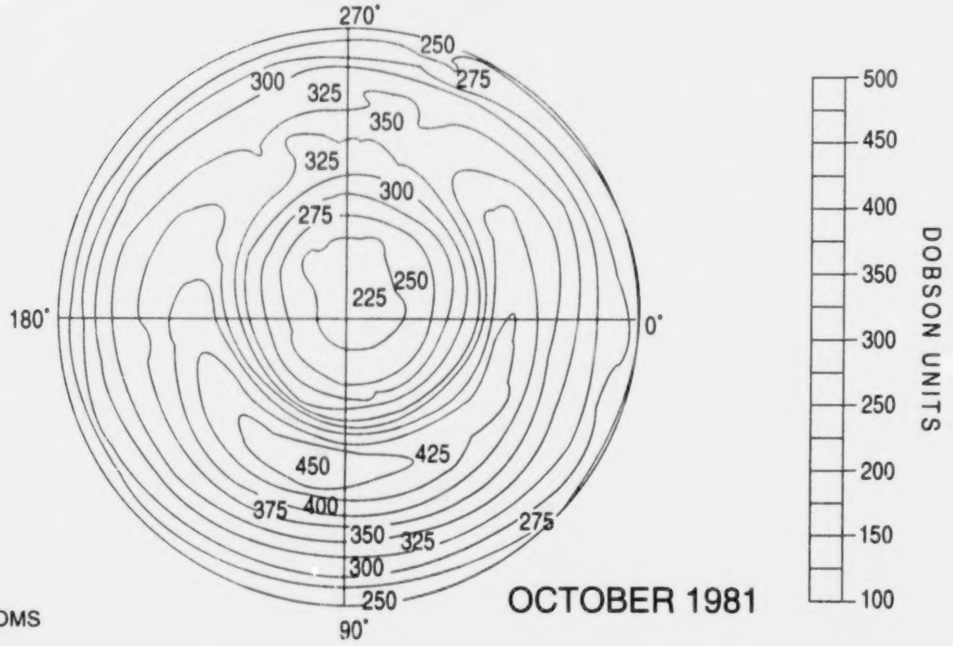
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

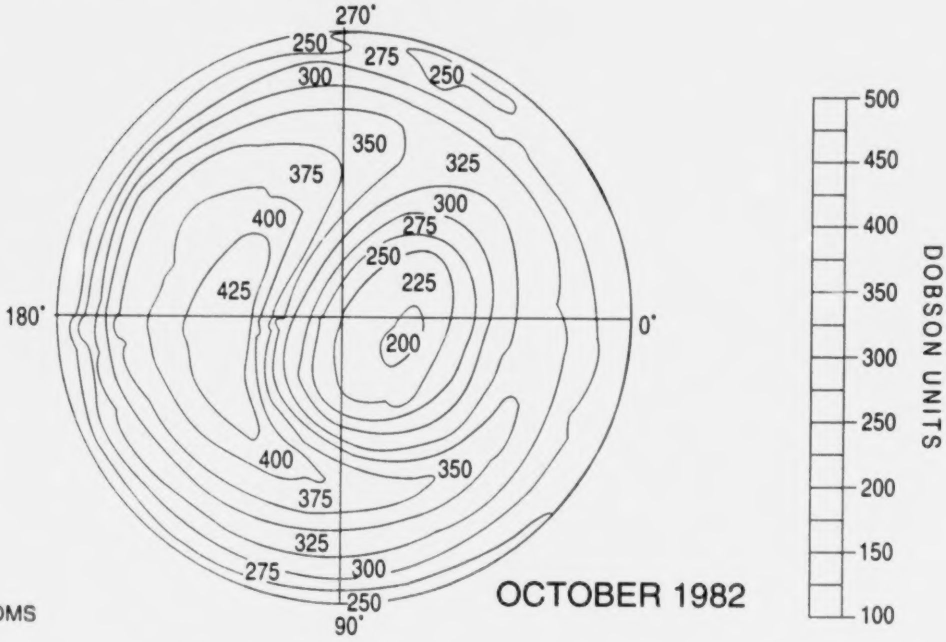
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN

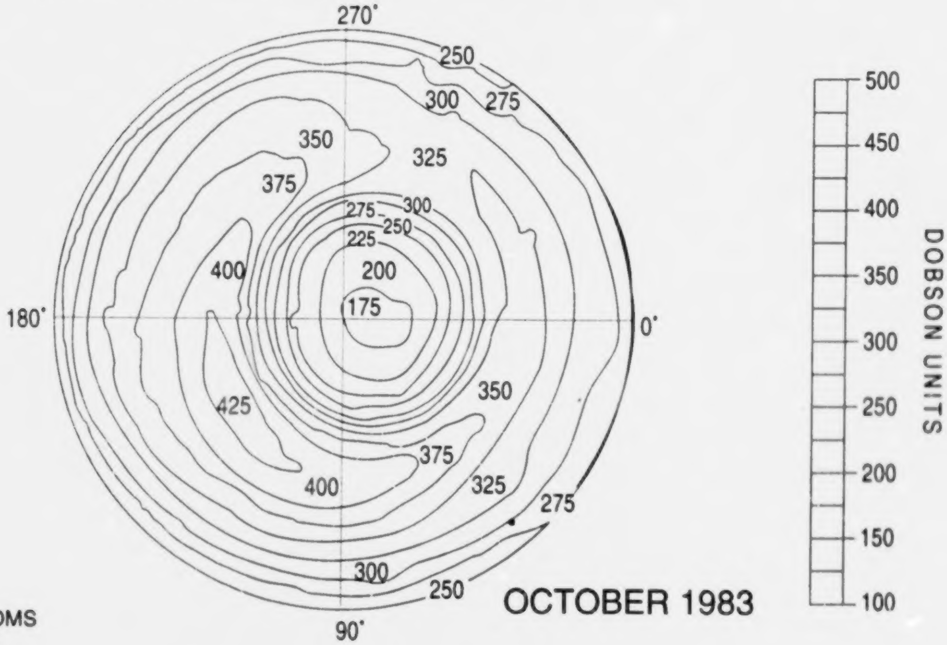


OCTOBER 1982

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN

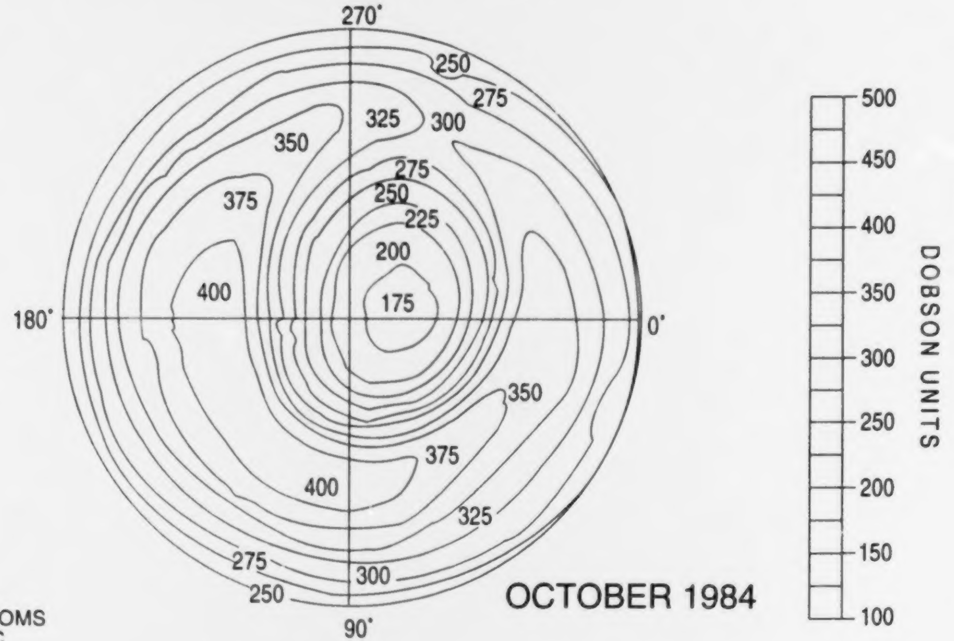


OCTOBER 1983

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

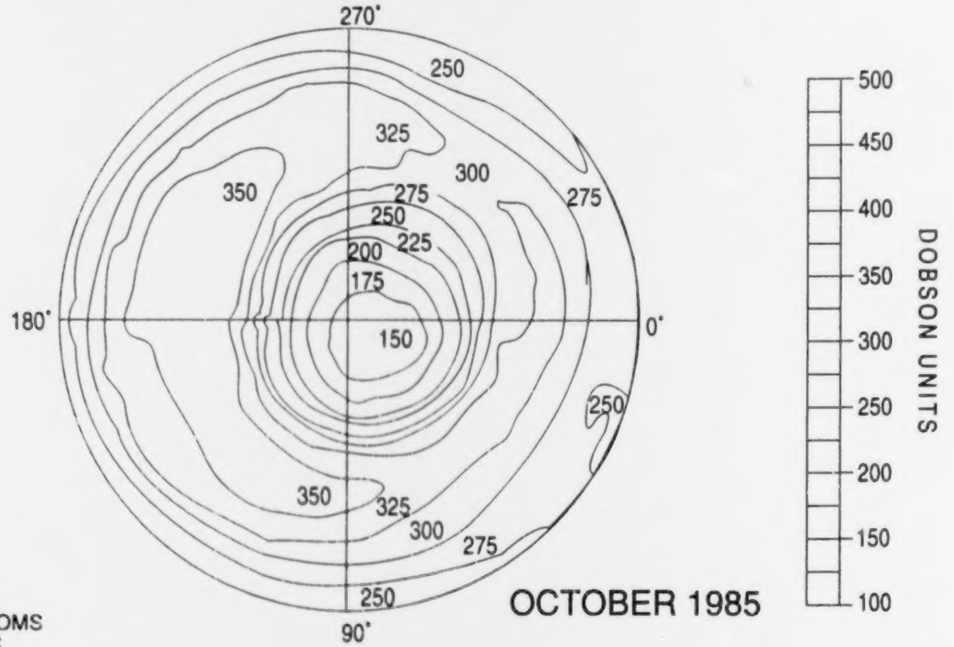
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

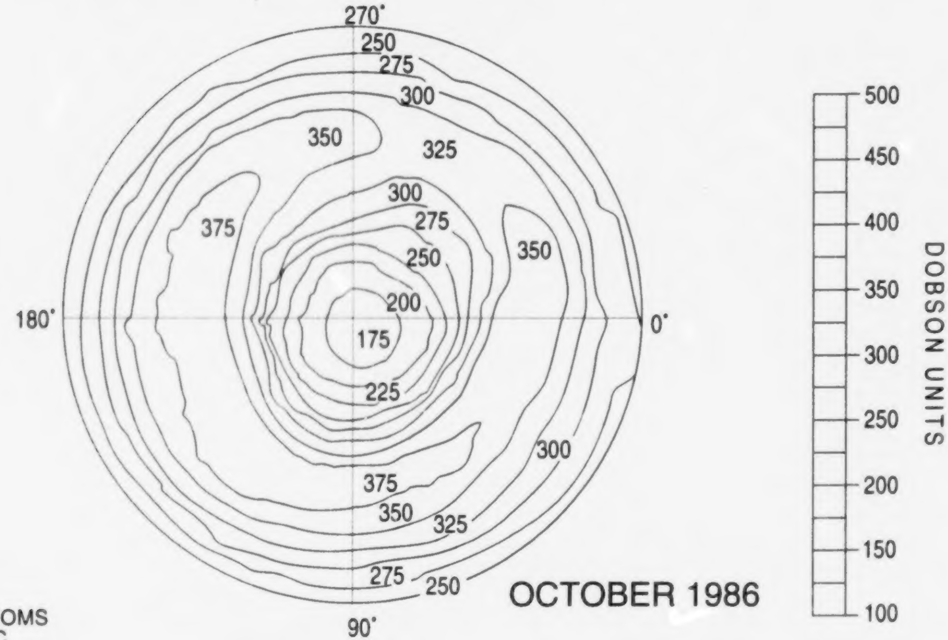
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN

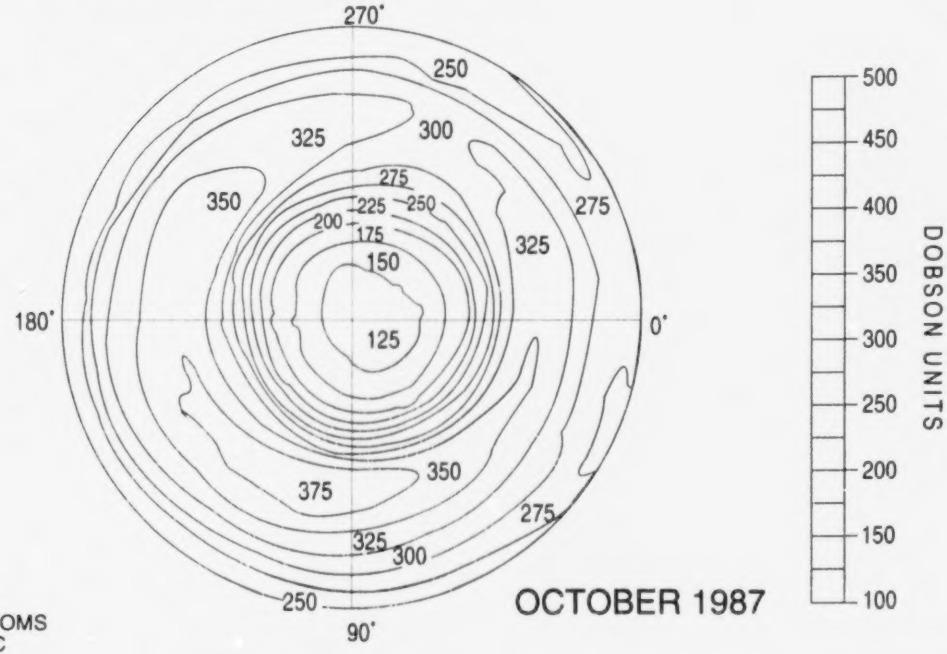


OCTOBER 1986

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN

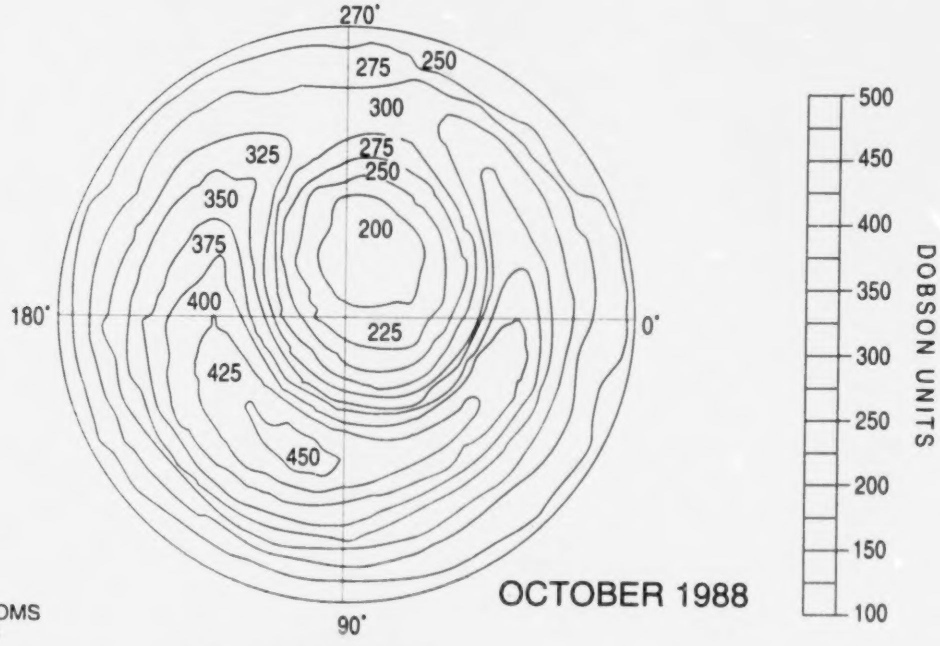


OCTOBER 1987

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN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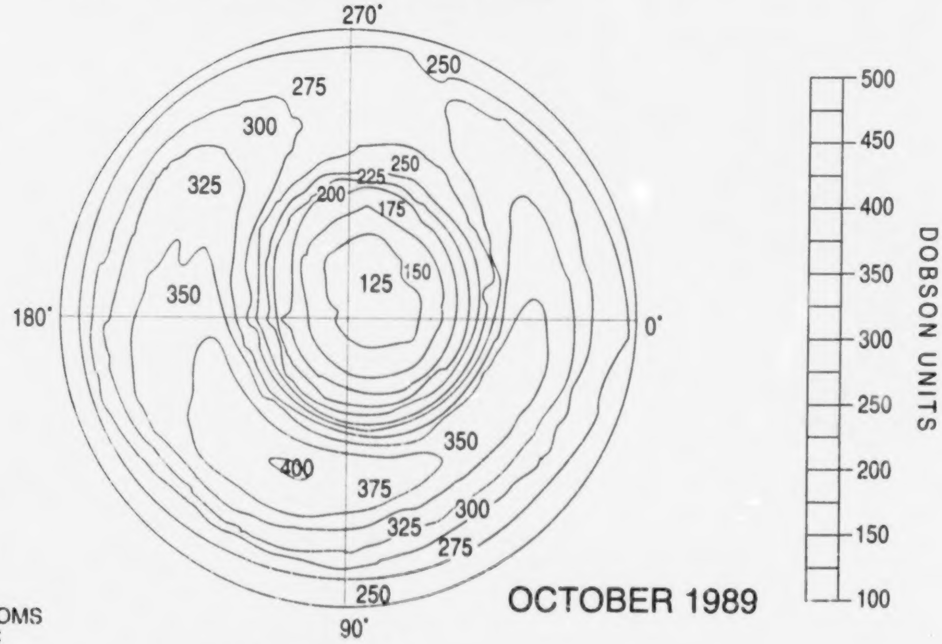
OCTOBER 1988

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN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OCTOBER 1989

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

OZONE TAG

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NAME: Jan Weathers Dykes

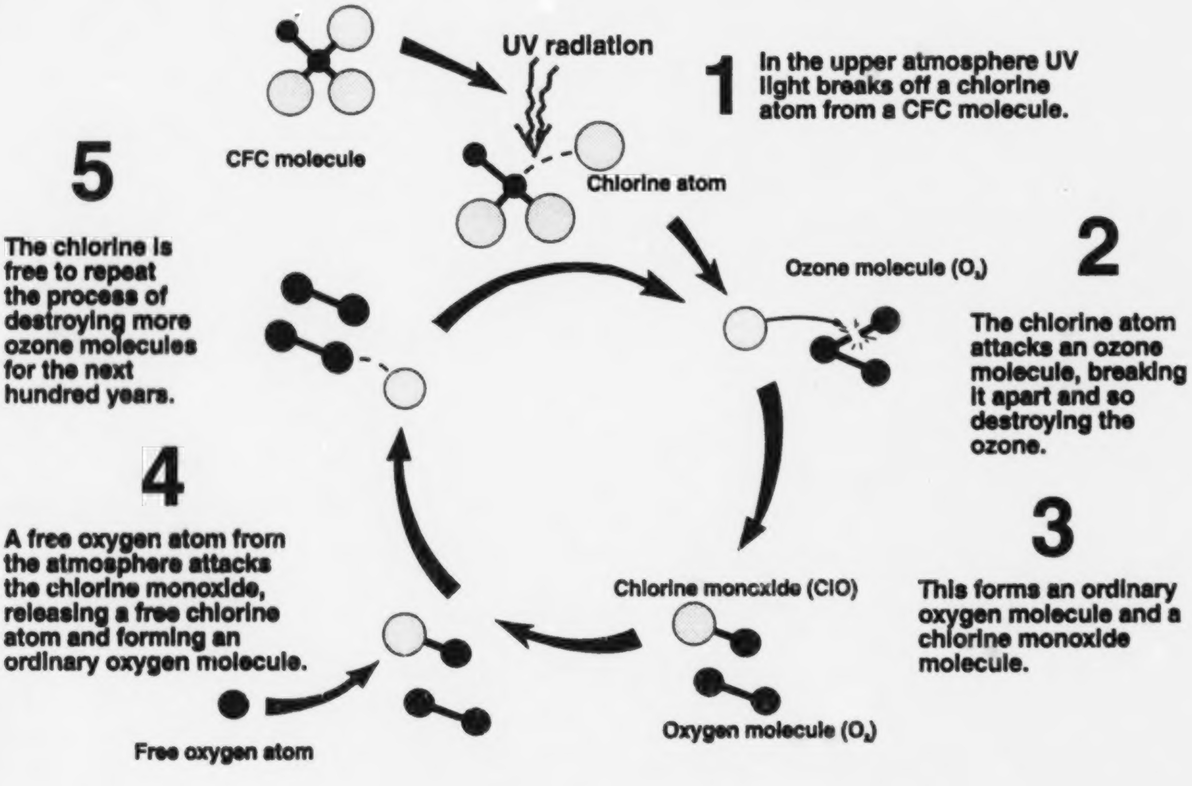
SCHOOL: Rosenwald Middle School

SCHOOL DISTRICT: Bay County

GRADE/SUBJECT: 6th Grade/General Science

TOPIC AND ISSUE STATEMENT: Ozone is a form of oxygen. The ozone found in the stratosphere screens ultraviolet radiation from the sun. Currently, man-made chemical compounds containing chlorine and bromine are attacking our stratospheric ozone. Chlorofluorocarbons and bromofluorocarbons are the most common. If this trend continues, more ultraviolet radiation will penetrate the stratosphere and reach the earth's surface. Increased ultraviolet radiation can cause skin cancer.

An understanding of the chemical reactions involved in ozone depletion can increase an individual's understanding of the entire phenomenon. This lesson is designed to teach the chemistry of ozone depletion in a simplified manner. The basic reaction chain which will be symbolized is pictured below.



1 In the upper atmosphere UV light breaks off a chlorine atom from a CFC molecule.

2 The chlorine atom attacks an ozone molecule, breaking it apart and so destroying the ozone.

3 This forms an ordinary oxygen molecule and a chlorine monoxide molecule.

4 A free oxygen atom from the atmosphere attacks the chlorine monoxide, releasing a free chlorine atom and forming an ordinary oxygen molecule.

5 The chlorine is free to repeat the process of destroying more ozone molecules for the next hundred years.

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Ozone Depletion

OBJECTIVES:

1. The student will be able to explain the role of stratospheric ozone.
2. The student will be able to predict at least three ways in which depleted ozone would change her/his lifestyle.
3. The student will be able to describe the process by which chlorine or bromine compounds can break down ozone molecules.
4. The student will be able to relate the amount of chlorine or bromine in the atmosphere to the rate of ozone depletion.

MATERIALS: Colored ribbon, chart paper, markers, paper, pencil, and stopwatch.

REFERENCES: What Would It Be Like To Live In A World Where The Sun Was Dangerous? pamphlet.

STRATEGY: This lesson will be taught after a general introduction of ozone depletion. It allows students to enhance their understanding before they do further exploration activities and begin to propose solutions. A basic understanding of atoms and molecules is a prerequisite.

ACTIVITY: The teacher will review the concept of ozone depletion, discussing major causes and resulting problems. The teacher will guide the students through the reactions associated with this process. (See Topic and Issue Statement.) Students will then go outside to play Ozone Tag.

For this game, one student will be designated as a chlorine atom which UV energy has released from a chemical compound. This student should use a piece of colored ribbon as an armband or headband. Other students should be oxygen atoms and should "number-off" from one to four. The ones, twos, and threes will link in groups of three by holding hands (⋎). They represent ozone molecules. Fours represent free oxygen atoms.

At a signal, the teacher will begin timing, and the chlorine atom will begin to pursue ozone molecules. The ozone molecules may try to avoid being captured but must stay linked. When the chlorine atom catches a member of the ozone molecule, that member must bond with the chlorine atom, leaving a diatomic oxygen molecule. ($CI + 0_3 \rightarrow CIO + 0_2$) All diatomic oxygen molecules should join both hands to represent double bonds (●=●). The chlorine atom and oxygen atom remain linked until the chlorine atom catches a free oxygen atom. Then the two oxygen atoms join in a double bond and the chlorine atom is free to attack another ozone molecule. This process should be followed until all ozone molecules have been broken down to diatomic oxygen molecules or diatomic oxygen molecules and one chlorine monoxide molecule (depending on the number of participants). The teacher, or a designated timekeeper, should record the amount of time required for one chlorine atom to break down all of the ozone. The game should then be repeated twice: with two chlorine atom pursuers and with three. The time needed to break down the ozone should be recorded each time.

After three games, the teacher and students will return to the classroom. The students will work cooperatively to graph the results of each game round on chart paper. This graph should illustrate that increased chlorine levels increases the rate of ozone destruction. Remind students that the atom could also be a bromine atom. The teacher can then review major ideas, linking them with the game.

EXTENSIONS:

1. Have students design a beach clothing line for the post-ozone era. How would styles change? Why?

2. Have students use colored marshmallows and pretzel sticks to construct molecules that show the reaction they acted out in the game.

3. Students can research products and companies to generate their own list of ozone-safe products in different categories (hairspray, deodorant, or other products).

EVALUATION: Students will answer the following questions:

1. Describe the importance of ozone within the stratosphere.

2. If ozone depletion continues, what are three lifestyle changes you will have to make? Why?

3. Explain the process by which bromine or chlorine atoms break down ozone. You can use pictures or examples from the game to help you explain.

4. What effect would increased chlorine levels have on ozone depletion?

V

ECOSYSTEM RESPONSE

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INFORMATION UNIT
ON CLIMATE CHANGE

Information Unit on Climate
Change, UNEP
P.O. Box 356, CH-1219
Chatelaine, Switzerland

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The impact of climate change on agriculture

▲ **Climate change would strongly affect agriculture, but scientists still don't know exactly how.** Most agricultural impacts studies are based on the results of general circulation models (GCMs – see fact sheet 14). These climate models indicate that rising levels of greenhouse gases are likely to increase the global average surface temperature by 1.5-4.5°C over the next 100 years, raise sea-levels (thus inundating farmland and making coastal groundwater saltier), amplify extreme weather events such as storms and hot spells, shift climate zones poleward, and reduce soil moisture. Impacts studies consider how these general trends would affect agricultural production in specific regions. To date, most studies have assumed that agricultural technology and management will not improve and adapt. New studies are becoming increasingly sophisticated, however, and "adjustments experiments" now incorporate assumptions about the human response to climate change.

▲ **Increased concentrations of CO_2 may boost crop productivity.** In principle, higher levels of CO_2 should stimulate photosynthesis in certain plants; a doubling of CO_2 may increase photosynthesis rates by as much as 30-100%. Laboratory experiments confirm that when plants absorb more carbon they grow bigger and more quickly. This is particularly true for C3 plants (so called because the product of their first biochemical reactions during photosynthesis has three carbon atoms). Increased carbon dioxide tends to suppress photo-respiration in these plants, making them more water-efficient. C3 plants include such major mid-latitude food staples as wheat, rice, and soya bean. The response of C4 plants, on the other hand, would not be as dramatic (although at current CO_2 levels these plants photosynthesize more efficiently than do C3 plants). C4 plants include such low-latitude crops as maize, sorghum, sugar-cane, and millet, plus many pasture and forage grasses.

▲ **Climate and agricultural zones would tend to shift towards the poles.** Because average temperatures are expected to increase more near the poles than near the equator, the shift in climate zones will be more pronounced in the higher latitudes. In the mid-latitude regions (45° to 60° latitude), the shift is expected to be about 200-300 kilometres for every degree Celsius of warming. Since today's latitudinal climate belts are each optimal for particular crops, such shifts could have a powerful impact on agricultural and livestock production. Crops for which temperature is the limiting factor may experience longer growing seasons. For example, in the Canadian prairies the growing season might lengthen by 10 days for every 1°C increase in average annual temperature.

▲ **While some species would benefit from higher temperatures, others might not.** A warmer climate might, for example, interfere with germination or with other key stages in their life cycle. It might also reduce soil moisture; evaporation rates increase in mid-latitudes by about 5% for each 1°C rise in average annual temperature. Another potentially limiting factor is that soil types in a new climate zone may be unable to support intensive agriculture as practised today in the main producer countries. For example, even if sub-Arctic Canada experiences climatic conditions similar to those now existing in the country's southern grain-producing regions, its poor soil may be unable to sustain crop growth.

▲ **Mid-latitude yields may be reduced by 10-30% due to increased summer dryness.** Climate models suggest that today's leading grain-producing areas — in particular the Great Plains of the US — may experience more frequent droughts and heat waves by the year 2030. Extended periods of extreme weather conditions would destroy certain crops, negating completely the potential for greater productivity through "CO_2 fertilization". During the extended drought of 1988 in the US corn belt region, for example, corn yields dropped by 40% and, for the first time since 1930, US grain consumption exceeded production. The poleward edges of the mid-latitude agricultural zones — northern Canada, Scandinavia, Russia, and Japan in the northern hemisphere, and southern Chile and Argentina in the southern one — may benefit from the combined effects of higher temperatures and CO_2 fertilization. But the problems of rugged terrain and poor soil suggest that this would not be enough to compensate for reduced yields in the more productive areas.

▲ **The impact on yields of low-latitude crops is more difficult to predict.** While scientists are relatively confident that climate change will lead to higher temperatures, they are less sure of how it will affect precipitation — the key constraint on low-latitude and tropical agriculture. Climate models do suggest, however, that the intertropical convergence zones may migrate poleward, bringing the monsoon rains with them. The greatest risks for low-latitude countries, then, are that reduced rainfall and soil moisture will damage crops in semi-arid regions, and that additional heat stress will damage crops and especially livestock in humid tropical regions.

▲ **The impact on net global agricultural productivity is also difficult to assess.** Higher yields in some areas may compensate for decreases in others — but again they may not, particularly if today's major food exporters suffer serious losses. In addition, it is difficult to forecast to what extent farmers and governments will be able to adopt new techniques and management approaches to compensate for the negative impacts of climate change. It is also hard to predict how relationships between crops and pests will evolve

For further reading:

Martin Parry, "Climate Change and World Agriculture", Earthscan Publications, 1990.

Intergovernmental Panel on Climate Change, "The IPCC Scientific Assessment" and "The IPCC Impacts Assessment", WMO/IPCC, 1990.

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Oceans and the carbon cycle

▲ **The oceans influence the climate by absorbing and storing carbon dioxide.** Climate change is caused by the accumulation of man-made carbon dioxide (CO_2) and other greenhouse gases in the atmosphere. The rate of accumulation depends on how much CO_2 mankind emits and how much of this excess CO_2 is absorbed by plants and soil or is transported down into the ocean depths by plankton (microscopic plants and animals). Scientists believe that the oceans currently absorb 30-50% of the CO_2 produced by the burning of fossil fuel. If they did not soak up any CO_2, atmospheric CO_2 levels would be much higher than the current level of 355 parts per million by volume (ppmv) — probably around 500-600 ppmv.

▲ **Plankton influence the exchange of gases between the atmosphere and the sea.** In any given region, the relative amounts of CO_2 contained in the atmosphere and dissolved in the ocean's surface layer determine whether the ocean-water emits or absorbs gas. The amount of gas dissolved in the water is in turn influenced by the amount of phytoplankton (microscopic plants, particularly algae), which consume CO_2 during photosynthesis. Phytoplankton activity occurs mostly within the first 50 metres of the surface and, although oceanographers don't fully understand why, varies widely according to the season and location. Some areas of the ocean do not receive enough light or are too cold. Other areas appear to lack the nutrients or trace minerals required for life, or zooplankton (microscopic animals) that feed on phytoplankton so limit the population growth of the latter that not all of the available nutrients are consumed.

▲ **Rather like a pump, plankton transport gases and nutrients from the ocean surface to the deep.** Their role in the carbon cycle is quite different from that of trees and other land plants, which actually absorb CO_2 and serve as a storehouse, or "sink", of carbon. Instead, ocean life absorbs CO_2 during photosynthesis and, while most of the gas escapes within about a year, some of it is transported down into the deep ocean via dead plants, body parts, faeces, and other sinking materials. The CO_2 is then released into the water as the materials decay, and most of it becomes absorbed in the sea-water by combining chemically with water molecules (H_2O). Although a small but possibly significant percentage of the sinking organic material becomes buried in the ocean sediment, most of the dissolved carbon dioxide is eventually returned to the surface via ocean currents — but this can take centuries or millennia.

ECOSYSTEM RESPONSE

▲ **Measuring the level of plankton activity in the ocean is difficult.** The rate at which plankton consume carbon dioxide and convert it into sugars for producing tissue and energy varies enormously. This makes it difficult to sample and estimate their annual consumption of CO_2. The enormous expanse and remoteness of the oceans (few oceanographers want to go to Antarctica in the middle of winter) also hampers sampling. Satellite pictures of chlorophyll (cell pigment that converts sunlight into energy) give a general idea of the amount of phytoplankton present, and oceanographers hope that future satellite measurements will further clarify the picture.

▲ **Climate change will affect plankton, and vice versa.** Warmer temperatures may benefit some species and hurt others. Changes in carbon dioxide levels may not have a direct impact, but related "feedback loops" could be important. For example, because plankton create a chemical substance called dimethylsulfide (DMS) that may promote the formation of clouds over the oceans, changes in plankton populations could lead to changes in cloudiness. At the same time, more clouds would reduce the amount of solar radiation reaching the oceans, which could reduce plankton activity. Another possible feedback could occur near the poles. If global warming causes sea ice to melt, more light would reach and warm the surface waters, either benefiting or damaging certain plankton. (The depletion of the ozone layer by CFCs also increases the amount of ultra-violet light reaching the surface, which could have negative effects on the plankton.)

▲ **Most scientists are sceptical about proposals to artificially increase CO_2 absorption by "fertilising" key ocean regions.** For example, because Antarctic phytoplankton are surprisingly sparse considering the quantity of available nutrients, a few scientists have theorised that fertilising the Southern Ocean with iron would boost populations and thus the amount of CO_2 absorbed from the atmosphere. Insufficient iron, however, is only one of many possible reasons for low biological activity in the Southern Ocean, and too much iron could poison some plankton. Computer models also indicate that an increase in plankton off Antarctica may not actually lower atmospheric carbon dioxide levels significantly over the next 100 years. But the real danger, of course, is that manipulating biological systems that are not thoroughly understood could have negative consequences just as easily as positive ones.

For further reading:

Berger, W.H., V.S. Smetack, and G. Wefer, (eds.), "Productivity of the Ocean: Present and Past", Wiley: New York (1989).

Mann, K.H. and J.R.N. Lazier, "Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans", Blackwell Scientific Publications: Boston (1991).

Schlesinger, W.H., "Biogeochemistry: An Analysis of Global Change", Academic Press: San Diego, CA (1991).

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CHAPTER 3

TERRESTRIAL PLANTS

A.H. Teramura (USA), M. Tevini (FRG), J.F. Bornman (Sweden), M.M. Caldwell (USA), G. Kulandaivelu (India), and L.O. Björn (Sweden)

1991 REPORT SUMMARY

The potential importance of current solar UV-B levels, even in the absence of further ozone reduction, has been demonstrated experimentally by reducing present day levels of solar UV-B radiation reaching the plants under investigation. It has been shown that plant growth, and in some cases photosynthesis, can be altered in seedlings. Whether this holds true for mature plants is not yet known, but these results indicate the potential importance of solar UV-B radiation even without ozone reduction.

Continued research on plant responses to UV-B radiation underscores the concern for agriculture, forestry, and natural ecosystems as the ozone layer is depleted. Yet, quantitative predictions are complicated by several factors, such as carbon dioxide concentration and temperature. These are relevant to global climatic change, and have been shown to influence the manner in which plants respond to increased UV-B radiation. For example, the stimulating effect of carbon dioxide enhancement may be altered by UV-B and may involve more than one photosynthetic process. Therefore, carbon dioxide may not fully compensate for negative UV-B effects. Temperature has also been shown to influence UV-B effects on growth and physiological processes in some of the species investigated. Other abiotic factors, such as heavy metals, may also modify UV-B influences on plants.

Recent measurements of the penetration of UV-B radiation into plant tissues have confirmed that internal changes in anatomical features and pigmentation vary among plant species. These changes result in alterations in plant response to UV-B radiation. Increased UV-B has also been shown to alter the biotic relationships of higher plants as demonstrated by the changes in plant disease susceptibility and the balance of competition between plant species.

More has been learned about the mechanisms of UV-B action. Both long-term UV-B irradiation of whole plants and short-term irradiation of chloroplasts may induce the synthesis of certain polypeptides in photosynthetic membranes that could play a role in mitigating UV-B damage. The influence of UV-B on growth appears to be mediated by phytohormones, either through photodestruction or enzymatic reactions. Whether other morphological responses to UV-B are also mediated by phytohormones remains to be demonstrated. Repair of DNA damage by photoreactivation has been clearly demonstrated in several plant systems. However, the limits of this photoreactivation capacity have not yet been determined.

Field and greenhouse studies have shown that growth and photosynthesis are negatively affected by enhanced UV-B radiation in some tree species such as the loblolly pine. Although little data are available for tropical species, preliminary greenhouse studies indicate that growth, photosynthesis, and yield decreased in some rice cultivars. Care should be taken in assessing and generalizing the results from particular plant species and cultivars to other species, since there appears to be a great range of UV-B responses among plants.

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1989 REPORT SUMMARY

Much of the research on the potential impacts of an increase in solar UV-B radiation has centered on the effects on plant growth and physiology under artificial UV-B irradiation supplied to plants in growth chambers or greenhouses. However, these artificial sources do not precisely match the solar spectrum. Due to the wavelength dependency of photobiological processes, weighting functions have been developed based on action spectra for specific responses to assess the biological effectiveness of the irradiation sources and of predicted ozone depletion. Recent experiments also have utilized ozone to filter natural solar radiation and simulate an environment of reduced UV-B for comparative purposes.

Overall, the effectiveness of UV-B varies both among species and among cultivars of a given species. Of those plants which have been tested, a large proportion exhibit reduced plant growth (plant height, dry weight, leaf area, etc.), photosynthetic activity, and flowering. Competitive interactions also may be altered indirectly by differential growth responses. Photosynthetic activity may be reduced by direct effects on the photosynthetic process or metabolic pathways, or indirectly through effects on photosynthetic pigments or stomatal function. The dose response of these changes has yet to be clearly demonstrated in most cases. Plants sensitive to UV-B may also respond by accumulating UV-absorbing compounds in their outer tissue layers, which presumably protect sensitive targets from UV damage. The key enzymes in biosynthetic pathways of these compounds have been shown to be specifically induced by UV-B irradiation via gene activation.

Few studies have documented the effects of UV-B on total plant yield under field conditions. One notable exception is a six-year field study with soybean demonstrating harvestable yield reductions under a simulated 25% ozone depletion. These effects are further modified by prevailing microclimatic conditions. Plants tend to be less sensitive to UV-B radiation under drought or mineral deficiency, while sensitivity increases under low levels of visible light. Further studies are needed to understand the mechanisms of UV-B effects and the interactions with present stresses and future projected changes in the environment.

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CHAPTER 4

AQUATIC ECOSYSTEMS

D.-P. Häder (FRG), R.C. Worrest (USA), and H.D. Kumar (India)

1991 REPORT SUMMARY

Aquatic ecosystems contribute more biomass (104 Gt/a) than all terrestrial ecosystems (100 Gt/a) combined. Recent work on UV-B effects has concentrated on inhibition mechanisms and field studies in the subpolar waters of Antarctica, because of its high productivity and the occurrence of the ozone hole over this region.

Phytoplankton organisms orient within the water column using external factors. However, mobility and orientation mechanisms are impaired by UV-B radiation. Because most organisms do not possess UV-B receptors, they cannot avoid deleterious wavelength radiation that (according to new measurements) penetrates deeper into the water column than what has been previously measured. New action spectra indicate that, in addition to DNA, other targets absorb UV-B radiation including intrinsic proteins of the photoreceptor and photosynthetic apparatus.

The inability to adjust their position within the water column causes massive inhibition of photosynthesis, measured both in field and laboratory studies. Only in a few cases have potential UV-B-inducible screening pigments been identified.

A large share of the nitrogen consumed by higher plants is made available by bacterial microorganisms, which have been found to be very sensitive to UV-B radiation. Losses in nitrogen fixation could be compensated by additional nitrogen fertilization. However, such actions could stress the capabilities of developing nations.

The role of DMS, released from plankton and macroalgae as aerosol and cloud nuclei, is of major concern. Most importantly, a UV-B-induced decrease in phytoplankton populations may have an impact on cloud patterns and concomitant global climate changes.

An increased understanding of Antarctic trophic dynamics suggests that the likelihood of direct UV-B radiation effects on consumers is small. Rather, it is the possibility of indirect effects that may significantly affect the Antarctic trophic structure, such as different species sensitivities to UV-B radiation, or decreases in total available primary production. Because more than 30% of the world's animal protein for human consumption comes from the sea, the human populations may also be affected by the direct and indirect consequences of increased solar UV-B radiation on aquatic food webs.

Another potential consequence of a decrease in marine primary productivity would be a reduction in the capacity of the ocean to absorb carbon dioxide. A hypothetical loss of 10% of the marine phytoplankton would reduce the oceanic annual uptake of carbon dioxide by about 5 Gt (an amount equal to the annual emissions of carbon dioxide from fossil fuel consumption). Uncertainties regarding the magnitude of increased levels of UV-B radiation on aquatic systems still remain, including problems of extrapolating laboratory findings to the open sea, and the nearly complete absence of data on long-term effects and ecosystem responses. Uncertainties and future research needs include adaptive strategies and the effects of cumulative UV-B radiative doses. Additional information is needed in several areas before a more reliable assessment of risks is possible.

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1989 REPORT SUMMARY

Current data suggest that predicted increases in UV-B radiation could have important negative effects on the marine environment. However, uncertainties regarding the magnitude of these effects still remain, including problems of extrapolating laboratory findings to the open ocean, and the nearly complete absence of data on long-term effects and ecosystem responses.

Planktonic marine organisms account for over half of the total global amount of carbon fixed annually (10^{11} tons). Any reduction in this productivity will undoubtedly affect global food supply and global climate. Both primary production and subsequent steps in biological food webs are sensitive to current UV-B levels, and are potentially endangered by expected increases in UV-B radiation.

UV-B radiation affects 1) adaptive strategies (e.g., motility, orientation), 2) impairs important physiological functions, (i.e., photosynthesis and enzymatic reactions), and 3) threatens marine organisms during their developmental stages (e.g., the young of finfish, shrimp larvae, crab larvae). In addition to DNA damage, UV-B radiation affects enzymes and other proteins, eliciting photodynamic responses. These effects can have a number of possible consequences for aquatic ecosystems:

- Reduction in biomass production, resulting in a reduced food supply to humans;
- Change in species composition and biodiversity;
- Decreased nitrogen assimilation by prokaryotic microorganisms, possibly leading to a drastic nitrogen deficiency for higher plant ecosystems, such as rice paddies; and
- Reduced sink capacity for atmospheric carbon dioxide, thereby augmenting the greenhouse effect.

However, additional information is needed before more reliable assessments of the UV-B radiative risks posed to the marine environment will be possible.

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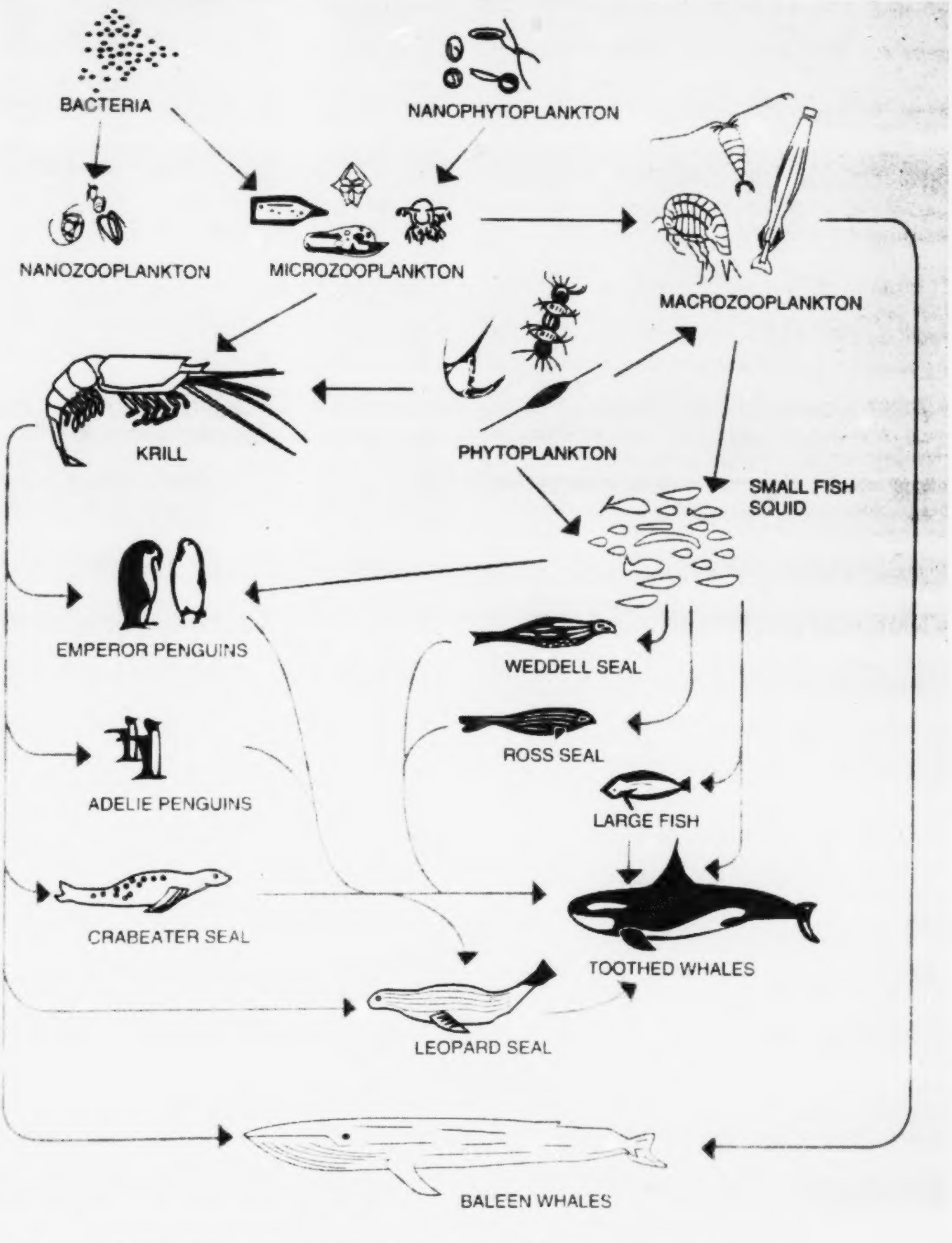
BACTERIA
NANOPHYTOPLANKTON
NANOZOOPLANKTON
MICROZOOPLANKTON
MACROZOOPLANKTON
KRILL
PHYTOPLANKTON
SMALL FISH
SQUID
EMPEROR PENGUINS
WEDDELL SEAL
ROSS SEAL
ADELIE PENGUINS
LARGE FISH
CRABEATER SEAL
TOOTHED WHALES
LEOPARD SEAL
BALEEN WHALES

Figure 4-3. A representation of the Antarctic marine food web (*Adapted from Voytek, 1990; used with permission*).

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CHAPTER 4

AQUATIC ECOSYSTEMS

D.-P. Häder (FRG), R.C. Worrest (USA), and H.D. Kumar (India)

SUMMARY

Current data suggest that predicted increases in UV-B radiation could have important negative effects in the marine environment. However, uncertainties regarding the magnitude of these effects remain large, including problems of extrapolating laboratory findings to the open sea, and the nearly complete absence of data on long-term effects and ecosystem responses.

Planktonic marine organisms account for over one-half of the total, global amount of carbon fixed annual (10^{11} tons). Any reduction in this productivity will undoubtedly affect global food supply and global climate. Both primary production and subsequent steps in biological food webs are sensitive to even current UV-B levels, and are potentially endangered by expected increases in UV-B radiation.

UV-B radiation 1) affects adaptive strategies (e.g., motility, orientation), 2) impairs important physiological functions, such as photosynthesis and enzymatic reactions, and 3) threatens marine organisms during their developmental stages (e.g., the young of finfish, shrimp larvae, crab larvae). In addition to DNA damage, UV-B radiation affects enzymes and other proteins, and elicits photodynamic responses. These effects can have a number of possible consequences for aquatic ecosystems:

- Reduction in biomass production, resulting in a reduced food supply to humans
- Change in species composition and biodiversity
- Decreased nitrogen assimilation by prokaryotic microorganisms, possibly leading to a drastic nitrogen deficiency for higher plant ecosystems, such as rice paddies
- Reduced sink capacity for atmospheric carbon dioxide, thereby augmenting the greenhouse effect

Additional information is needed before more reliable assessments of the risks posed to the marine environment from increasing UV-B radiation will be possible.

INTRODUCTION AND BACKGROUND

Photosynthetic organisms on our planet are estimated to fix about 10^{11} tons of carbon annually. This enormous mass can be visualized by a coal train that spans the distance from the earth to the moon and back five times. Less than one-half of this is due to photosynthesis in all higher plants (i.e., crops, forests, grassland, tundra, etc.). Planktonic organisms in the oceans fix the remaining amount of carbon dioxide.

Solar UV-B radiation penetrates deep into the zone where the organisms live. If increased UV-B impairs the productivity of the organisms, the effects may be dramatic both for the intricate marine ecosystem and for humans, who are affected by this system. More than 30% of the world's animal protein for human consumption comes from the sea; in many countries, this percentage is significantly larger. Any reduction of this productivity will undoubtedly affect global food supply. In addition, a decrease in the size of the phytoplankton populations will result in a higher CO_2 concentration in the atmosphere, which will augment the CO_2 increase caused by fossil fuel burning. This consequence of stratospheric ozone depletion is not yet accounted for by the current climate change/greenhouse effect models.

Research on marine ecosystems is needed to improve our understanding of how stratospheric ozone depletion could influence the world food supply. Past efforts have addressed the physical variables that determine the exposure (or dose) to the systems, as well as the amount of UV-B radiation that produces biological effects. Studies also have addressed the direct effects on the sensitive life stages of ecologically important marine organisms, and the extent to which the additive effects might impact marine resources that are significant to man. The sum of past efforts suggests that the likelihood of a significant impact resulting from UV-B exposure to marine environments is real, even if it cannot yet be fully quantified.

The different sensitivity of the primary producers (e.g., phytoplankton) and of the primary consumers (e.g., zooplankton) to UV-B radiation will result in altered species composition within these communities. Any increase in the radiation level is also likely to decrease the overall productivity. Both factors will introduce instabilities in ecosystems and will likely have an influence on higher levels within the food web. The biological food web in both freshwater and marine ecosystems starts with the primary producers – mainly the phytoplankton *(Figure 4.1)*. Primary consumers utilize the biomass the phytoplankton produce, and are themselves food input for the next level in the food web.

Because of their need for the sun's energy, phytoplankton are restricted to the upper layers of their oceanic environment. Mutual shading, absorption, and light scattering prevent effective light penetration below a certain depth where phytoplankton cannot survive. The penetration of light into a body of water strongly depends on the characteristics of the water. Water can range from turbid coastal waters to clear blue oceanic waters. In addition, light penetration depends on the wavelength of the radiation; shortwave violet and longwave red light are more strongly absorbed than blue-green light *(Figure 4.2) [Jerlov, 1970]*. Even though partially attenuated, a fair amount of solar UV-B radiation penetrates into the photic zone *[Worrest, 1986]*. This presents a potential hazard for the planktonic organisms, because they do not possess the protective epidermal UV-absorbing layers that are characteristic of higher plants and animals. For most of the observed effects in planktonic organisms studied to date, visible radiation and longer wavelength UV-A radiation (315-380 nm) may not be as effective.

Ambient or slightly increased doses of UV-B radiation can decrease phytoplankton primary production *[Worrest, 1986; USEPA, 1987]*. Currently, no quantitative assessment of the loss in biomass production in aquatic systems is available. However, even a small loss will have a noticeable adverse effect. The annual biomass

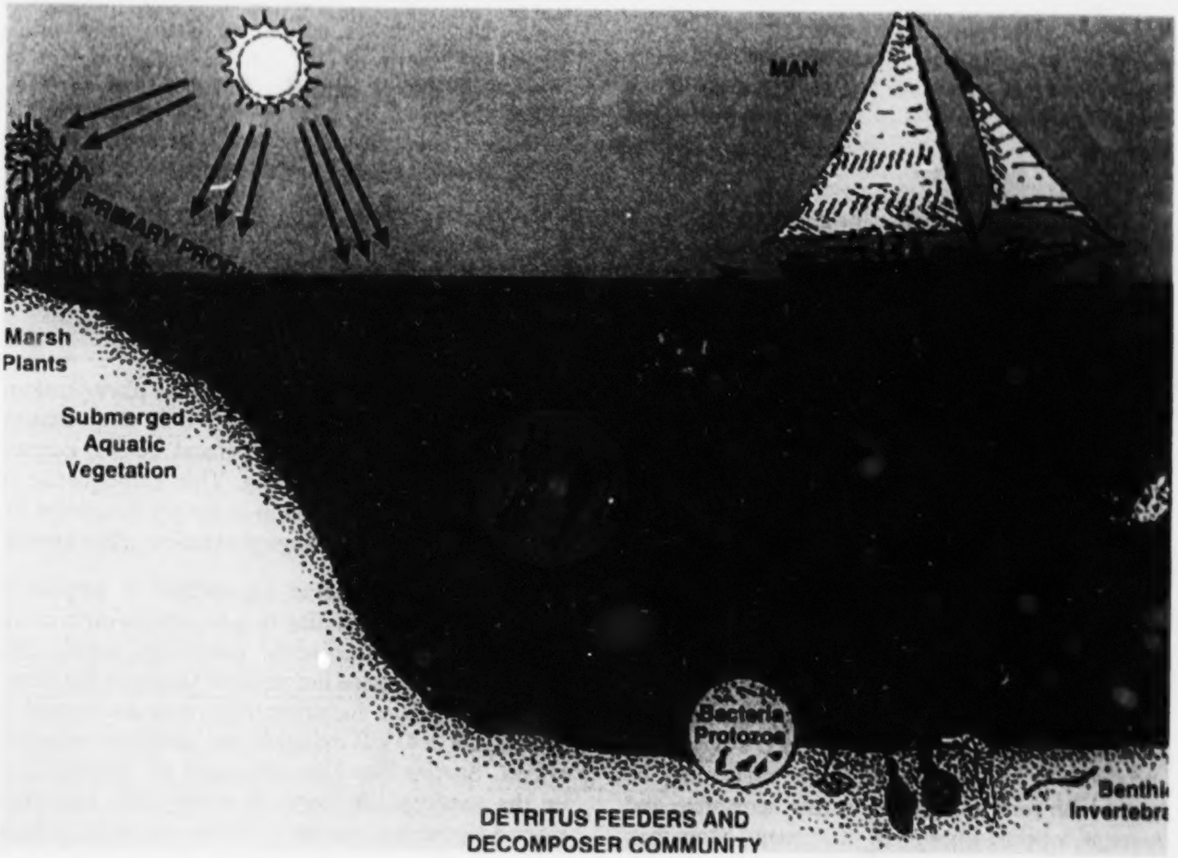
MAN
PRIMARY PRO
Marsh Plants
Submerged Aquatic Vegetation
Bacteria Protozoa
Benthi Invertebra
DETRITUS FEEDERS AND DECOMPOSER COMMUNITY

Figure 4.1
Example of the biological food web in a marine ecosystem, which starts with the primary producers; the biomass they produce is utilized by the primary consumers, which in turn serve as food input for the next level in the food web.

production by phytoplankton can be calculated as about 6×10^{14} kg. A loss of 10% would far exceed the gross national product of all countries in the world, assuming any reasonable price for biomass on the market.

STATE OF THE SCIENCE

Primary Producers: Phytoplankton

Ultraviolet radiation damage to the primary producers will have dramatic consequences because these organisms produce more than one-half of the earth's biomass. In addition, a large food web of dependent organisms relies upon the productivity of the phytoplankton. The first evaluations were performed on laboratory test systems, the physiology of which was well known and for which stress situations could easily be determined experimentally. Most initial studies used UV-B radiation from artificial sources producing a spectrum that deviated significantly from natural solar radiation both quantitatively and qualitatively. One important group of phytoplankton, the nanoplankton (defined by its extremely small size), has not yet been studied in any detail. Factors that control the adaptation of phytoplankton to constantly changing environmental conditions are the most important vital attributes for their survival.

Planktonic organisms are not equally distributed in the water column. They orient with respect to external factors such as light, gravity, chemical gradients, temperature and the earth's magnetic field *[Nultsch and Häder, 1988]*. Experiments in laboratory and natural situations have shown that solar UV-B radiation drastically affects orientation, motility and development in these organisms even after short exposure times. This reduces the chances for growth and survival of the populations. More recent experiments have shown that UV-B radiation affects the general metabolism, photosynthetic energy production, and nitrogen fixation and assimilation in many species.

Motility

Motility and orientation are vital prerequisites for adaptive defense mechanisms in phytoplankton and are, thus, the basis for survival and productivity. Recent studies have shown that UV-B radiation impairs motility in a number of motile microorganisms as diverse as prokaryotic (bacteria-like) blue-green algae, unicellular flagellates, and gliding green algae *[Häder, 1988; Häder and Häder, 1988a,b, 1989]*. When exposed to unfiltered solar radiation, the percentage of motile flagellates decreases within a few hours. Likewise, the speed of movement is drastically reduced by the radiation. These responses are not due to overheating, because thermal effects have been excluded by irradiating the organisms in temperature-controlled growth chambers. Eliminating the exposure to UV-B radiation either by inserting suitable filters or by artificially introducing a thicker layer of ozone results in far better motility. This response indicates that the solar UV-B radiation is responsible.

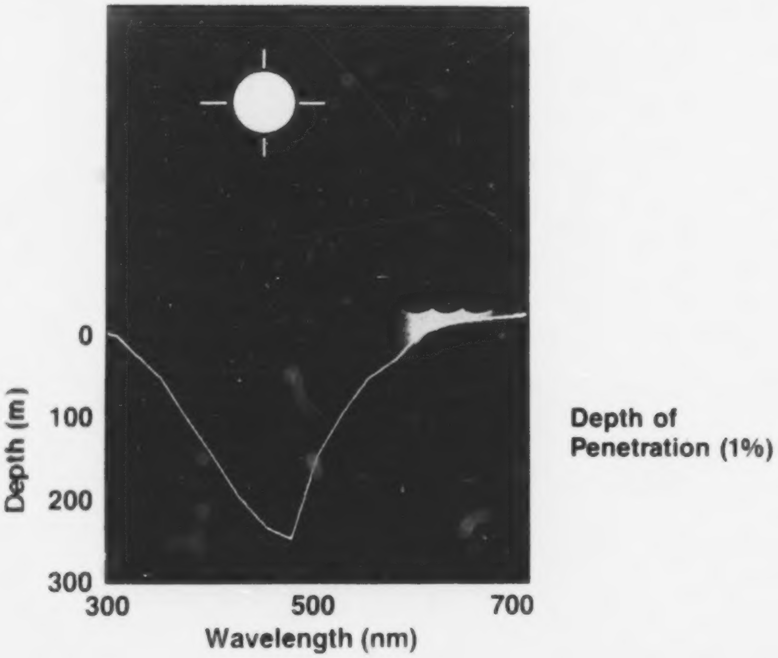

Figure 4.2
Penetration of radiation into oceanic waters relative to wavelength [data from Jerlov, 1970, and Baker and Smith, 1982].

Inhibition of the cellular locomotion apparatus prevents the organisms from escaping hazardous environments, e.g., bright white light and UV-B radiation *[Häder, 1988a]*. The results indicate that motility is affected even at ambient UV-B levels. In addition to temperature, nutrition, and other stress factors, solar UV-B radiation may be one of the factors that decreases algal growth during summer (algal blooms occur mostly in spring and in autumn).

Orientation

Most motile microorganisms do not possess a sensor for UV-B radiation, but rather use various bands in the visible and long-UV range for photoorientation *[Foster and Smyth, 1980]*. Studies have shown that their orientation mechanisms are affected by UV-B radiation, even after short exposure times. Any decrease in orientation of motile phytoplankton prevents the necessary constant adaptation to the changing environmental conditions and possibly hazardous situations.

The organisms have a repertoire of several responses to light, which are often antagonistic and allow a fine tuning of orientation *[Häder, 1988]*. Some flagellates move toward the light source at low light intensities. This brings the population toward the surface where they receive sufficient solar radiation for photosynthesis. At high light intensities, most organisms escape from the light source. This is ecologically important because excessively intense irradiation bleaches the photosynthetic pigments of many phytoplankton *[Kamiya and Miyachi, 1984; Häder et al., 1988; Nultsch and Agel, 1986]* and damages cellular structures *[Spikes and Straight, 1981]*. Another important strategy for orientation is the response to gravity *[Häder, 1987b; Kessler, 1986]*, by which the organisms orient in space and move toward the surface even in the absence of light.

The various orientation strategies result in the movement of populations to specific, suitable horizons in their environment. These horizons fluctuate in a body of water as a result of changing environmental conditions, and many planktonic organisms are known to undergo daily vertical movements of up to 12 m *[Burns and Rosa, 1980]*. Researchers have studied the motility patterns of microorganisms by placing populations in vertical transparent plexiglas columns immersed in a pond or lake *(Figure 4.3)*. The movements of the organisms in response to the external conditions were followed and the cell densities were determined *[Häder and Griebenow, 1987, 1988]*. Currently, even larger columns are being constructed to follow the movement patterns of phytoplankton in their environment and their response to UV-B exposure.

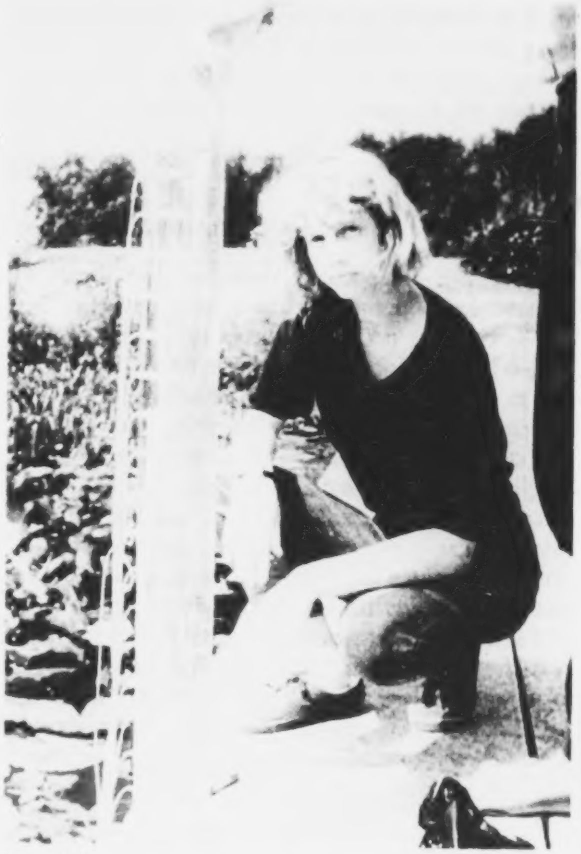

Figure 4.3
A plexiglas column is used to study the vertical movements of phytoplankton in response to changing light conditions. The column is immersed in a natural habitat.

Development and Physiology

Most microorganisms undergo a developmental cycle. During some stages of the cycle, the organisms are more vulnerable to solar UV-B radiation than during others. This can be due to a higher sensitivity or a more exposed position in the water column. Any inhibition of one of the developmental stages or physiological functions has long-lasting effects on productivity and reproductive capacity of the whole population. UV-B inhibition of development also can cause a drastic change in the species composition of phytoplankton, which in turn may affect energy transfer through the food web. Loss of certain algal species and predominance of toxic or non-palatable organisms may interfere with growth and multiplication in organisms higher in the food web.

- *General Metabolism.* At sublethal exposure levels, UV-B radiation causes intracellular damage and affects growth and the endogenous rhythms found in many microorganisms *[Worrest, 1982]*. This low level of UV radiation damages proteins, but the proteins can be replaced by dark and light repair mechanisms. Higher doses affect the cellular membrane's permeability to important chemicals and induce irreversible damage to proteins, eventually causing death *[Döhler, 1984]*.

- *Photosynthesis.* Enhanced UV-B radiation reduces the concentration of photosynthetic pigments and decreases the production of ATP and NADPH, which in turn affects the general CO_2 fixation. Specifically, the photosystem II reaction center is damaged, accompanied by a structural change in the membranes and a decrease in the lipid content. Any change in nucleic acids and protein composition affects enzyme activity and production *[Döhler et al., 1986]*.

- *Nitrogen Assimilation.* Nitrogen assimilation is one of the key processes for growth because it determines the rate of protein synthesis. In addition, prokaryotic organisms such as cyanobacteria are capable of utilizing atmospheric nitrogen dissolved in water – a metabolic mechanism that higher plants cannot perform. Thus, cyanobacteria have an important role in providing nitrogen for higher plants (e.g., in tropical rice paddies). The annual nitrogen assimilation by this group of organisms alone has been assumed to amount to 35 million tons, which exceeds the 30 million tons of artificial nitrogen fertilizer produced annually.

The key enzyme for nitrogen assimilation is nitrogenase. Light activates nitrogenase and UV-B radiation inactivates it *[Döhler, 1985]*. Subsequent enzyme activity incorporates nitrogen into precursors, and eventually into amino acids and proteins. Studies have found that UV-B radiation drastically affects these processes in a number of ecologically important phytoplanktonic species *[Döhler et al., 1987]*.

Pigmentation and Fluorescence

Unlike land plants, most phytoplankton are not capable of tolerating excessive solar radiation. When exposed to full sunlight the photosynthetic pigments are bleached *[Nultsch and Agel, 1986; Häder et al., 1988]* and the organisms die within a few days. Some of the accessory pigments, which play a role in light harvesting for photosynthesis, are bleached within 15 minutes of exposure to full sunlight *(Figure 4.4)*. The chlorophylls usually have a lifetime of several hours at constant exposure. Using UV-B radiation from artificial sources has shown that the photosynthetic pigments also are bleached by the UV-B component alone, indicating the detrimental effect of this radiation on photosynthesis.

Following a short exposure to UV-B radiation, a strong increase in fluorescence by the phytoplankton occurs. This reemission of light energy demonstrates that the photosynthetic apparatus did not effectively use the photosynthetic light but rather wasted it in fluorescence. After longer exposure times, the fluorescence decreases again, indicating that radiation increasingly destroys the absorbing pigments. Pigment concentration can be determined in laboratory samples and also in natural plankton communities from satellite measurements using spectroscopic data *[Jeffrey and Humphrey, 1975]*.

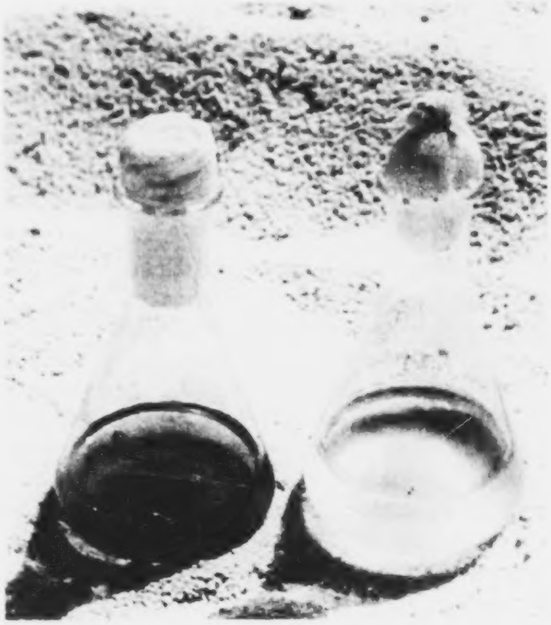

Figure 4.4
When exposed to strong sunlight, phytoplankton populations are bleached within a short time (right flask), which can be seen even visibly when compared with a population kept under dim light (left flask).

UV-B Targets

Most action spectra for biological damage measured suggest that short wavelength UV-B radiation below 300 nm is most effective. Thus, any long-term decrease in the ozone layer causing an increase in this radiation is likely to have adverse effects for biological systems. Several components of the system are sensitive to the UV-B radiation, as described in the following sections.

- *DNA.* DNA can be the primary UV target in some microorganisms *[Yammamoto et al., 1983]*. Some of these conclusions have been determined primarily from the similarity between action and absorption spectra. In a recent study of a green flagellate, however, DNA does not seem to be the major target for UV-B radiation *[Häder and Häder, 1988a]*. The conclusion is based on the very fast effect of the radiation on motility and the fact that no photorepair has been observed. This mechanism relies on the activity of an enzyme that removes the lesions produced by high-energy UV radiation and is activated by long wavelength UV-A (315-380 nm) or visible radiation *[Hirosawa and Miyachi, 1983]*. After inducing UV-B damage, no recovery could be found in dim white light. These results argue against an involvement of DNA in these particular organisms. The same result was found in gliding cyanobacteria *[Häder et al., 1986]*.

- *Photodynamic Responses.* One of the mechanisms by which high-energy radiation can damage cells and tissues is by photodynamic responses *[Ito, 1983]*. In this response, a photoreceptor molecule absorbs a high energy photon and uses the energy for the production of singlet oxygen *[Maurette et al., 1983]* or free radicals *[Spikes, 1977]*. These substances destroy membranes and other cellular components. In some studies, however, photodynamic reactions could be excluded as the main mechanism of UV-B radiation damage by using diagnostic reagents and quenchers for singlet oxygen and free radicals *[Häder et al., 1986; Häder and Häder, 1988b]*.

- *Other UV-B Targets.* In those organisms for which neither DNA nor photodynamic responses are involved, specific targets that are responsible for UV-B inhibition need to be identified. The primary targets could be the receptor molecules for photoorientation or specific components of the motor apparatus.

Consumers: Marine Animals

For the consumer components of marine ecosystems, various experiments have demonstrated that UV-B radiation causes direct damage to juvenile fish, shrimp larvae, crab larvae, and other small animals essential to the marine food web. These damaging effects include decreased reproductive capacity, growth, survival, and other reduced functions *[Worrest, 1986]*. Although not as important as light, temperature or nutrient levels, evidence indicates that ambient solar UV-B radiation is currently an important limiting ecological factor. Even small increases of UV-B exposure could result in significant ecosystem changes *[Damkaer, 1982]*.

Effects on Zooplankton

Marine invertebrates differ greatly in their sensitivity to UV-B radiation. For example, one small crustacean suffers 50% mortality from UV-B radiation dose rates that are smaller than those currently present at the sea surface. By contrast, some shrimp larvae tolerate dose rates at the sea surface greater than those forecast for a 16% ozone depletion.

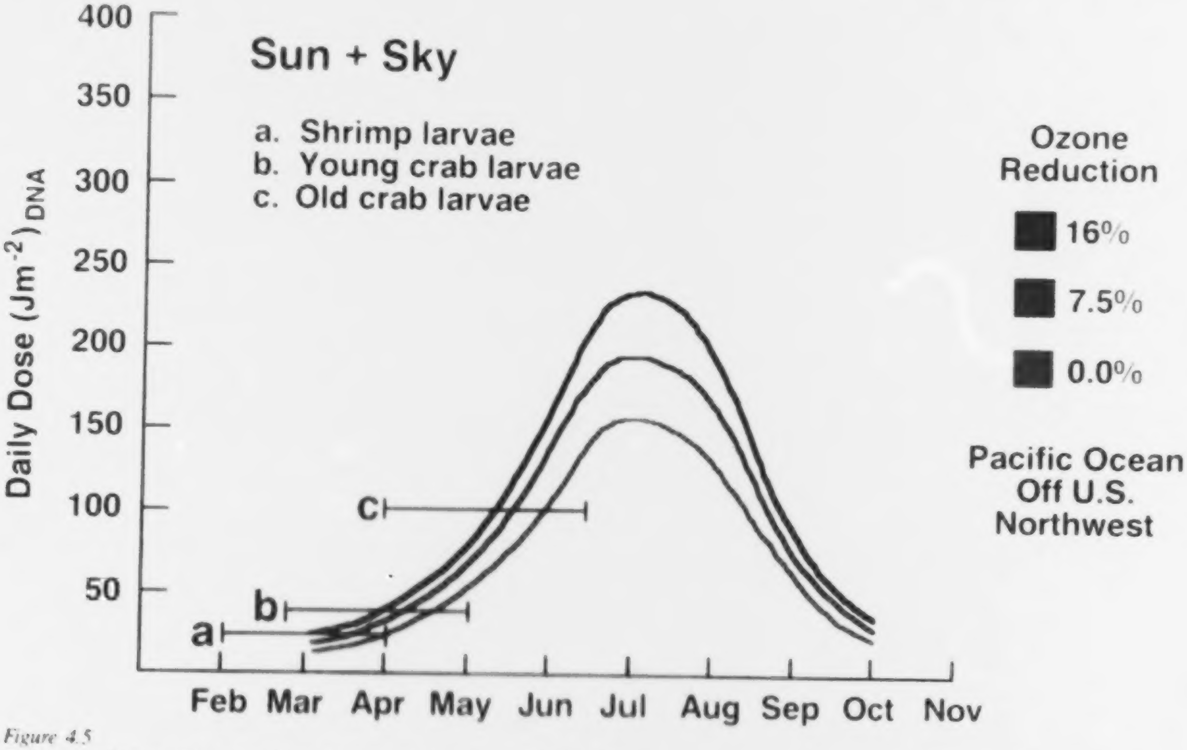

Figure 4.5
Estimated effective UV-B solar daily dose at various atmospheric ozone concentrations. Also shown are approximate thresholds of UV-B daily dose for shrimp and crab larvae, in natural seasonal position [adapted from Damkaer et al., 1981].

Larval shrimp exhibit a mortality threshold of 22 J m^{-2} day^{-1} (DNA weighted, 4-day exposure) *[Dey et al., 1988]*. This threshold is close to the reported UV-B dose near the surface of the sea in spring, but is exceeded during the longer days of summer at mid-latitudes *(Figure 4.5)*. Larval crabs have a slightly higher threshold sensitivity to UV-B radiation (36-100 J m^{-2} day^{-1} for 6-20 day exposures) *[Damkaer and Dey, 1983]*. These threshold levels are higher than those produced by existing and anticipated ozone levels for spring spawners, but they are well below the 150 J m^{-2} day^{-1} possible at similar latitudes in mid-summer, even without ozone depletion. With a 16% ozone depletion over temperate pelagic waters, a lethal (50% mortality) cumulative radiation dose for about half the zooplankton species examined would be reached at a depth of 1 m in less than five days in summer.

Field investigations and laboratory experiments with freshwater crustaceans *(Daphnia sp.)* have shown big differences in UV-B sensitivity between different species probably due to different pigmentation and to various capacity for reactivation *[Siebeck and Böhm, 1987]*.

Effects on Fisheries

UV-B stress is most likely to affect fisheries in two ways: through eggs and larvae, and through effects on the food chain upon which the juvenile fish depend. The bulk of the world's marine harvest of fish, shellfish, and crustaceans consists largely of species that have eggs and larvae at or near the sea surface where they would be exposed to increasing levels of UV-B radiation *[Hardy, 1982]*.

Enhanced solar UV-B radiation directly reduces the growth and survival of larval fish *[see Hunter et al., 1982]*. Based on these data for a region of the North American pacific coastal shelf in June, a 16% ozone reduction would result in increases in larval mortality of 50%, 82% and 100% at the 0.5-m depth for anchovy larvae of ages 2, 4 and 12 days, respectively. Anchovy larvae occur in many regions coincident with high radiation levels between June and August with a peak in July. Because virtually all anchovy larvae in the shelf areas described occur within the upper 0.5 m, a 16% ozone reduction level could lead to large increases in larval mortality.

Evidence indicates that increased UV-B irradiance could also result in fishery losses through indirect effects on the planktonic food web. Based on one assessment, a 5% decrease in primary production (estimated for a 16% ozone depletion) would reduce fish yield by approximately 6 to 9%. A 7% reduction in fish yield, if it occurred on a global basis, would then represent a loss of about 6 million tons of fish per year.

Risk of UV-B Damage

The biological effects of small changes in UV-B irradiance at the ocean surface will be very difficult to determine because marine ecosystems have an extremely large physical and biological "noise" level. Storms, clouds, and global currents cause dramatic changes in the status of marine life, and they are currently unpredictable. However, one should not conclude that changes that are lost in the noise of the system are insignificant simply because they cannot be measured or defined exactly. Changes that occur because of small systemic events (e.g., higher UV-B exposure) could accumulate in time to produce much more significant changes in marine organisms that appear very sensitive to current UV-B exposure.

The possibility exists that changes outside the historical range of UV-B exposure could have implications far greater than we are currently able to predict with confidence. At this time, conclusions about what could happen if levels of UV-B exposure increase cannot be drawn. An increase in UV-B exposure might have small effects or it might be much more significant.

Change in Species Composition

In marine plant communities, a major change in species composition – in addition to a global decrease in net production – might result from enhanced UV-B exposure *[USEPA, 1987]*. A change in community composition at the base of food webs may produce instabilities within ecosystems affecting organisms higher in the food web *[Kelly, 1986]*. The generation time of marine phytoplankton is in the range of hours to days; whereas the potential increase to ambient levels of solar UV-B irradiance resulting from stratospheric ozone depletion would occur in the range of decades. The question remains as to whether the gene pool within species is variable enough to adapt during this relatively gradual change in exposure to UV-B radiation (with respect to the generation time of the target organisms). Indirect effects also may occur in the form of altered patterns of predation, competition, diversity, and trophic dynamics if species resistant to UV-B radiation were to replace sensitive species. The combined effects of direct (larval mortality) and indirect (food web) losses cannot as yet be predicted, nor have assessments been made of adaptive strategies or genetic selections that could minimize population or ecosystem effects.

Loss in Nitrogen for Higher Plants

Cyanobacteria play a role in nitrogen fixation, especially in tropical rice paddies. Some of these organisms are extremely sensitive to current levels of UV-B exposure *[Häder et al., 1986]*. A significant decrease in the nitrogen fixation by prokaryotic microorganisms will affect growth and productivity of higher plants. The amount of artificial nitrogen fertilizer necessary to compensate for a substantial loss will stress the capabilities of lesser developed countries.

Atmospheric CO_2 Concentration and Global Climate Change

Another important consequence of a decrease in phytoplankton growth is the reduction in the important marine sink for carbon dioxide. The fluxes of carbon dioxide show that the oceans take up a major proportion of the carbon dioxide released annually. A 10% decrease in the carbon dioxide uptake by the oceans would leave about the same amount of carbon dioxide in the atmosphere as is produced by fossil fuel burning. This effect would have long-term consequences for the global climate and would enhance the predicted sea level rise.

In addition, if UV-B radiation inhibits dimethyl sulfide (DMS) production by marine phytoplankton, this could result in a reduction in the formation of atmospheric cloud condensation nuclei, decreased cloudiness, increased incident solar radiation including UV-B radiation – a positive destructive feedback loop. However, an alternative prediction argues that a substantial warming of the atmosphere would increase the evaporation from the oceans and thus cause a more massive cloud formation.

ASSESSMENT OF RESULTS

For components of marine ecosystems, various experiments have demonstrated that UV-B radiation causes damage to fish larvae and juveniles, shrimp larvae, crab larvae, other small animals, and plants essential to the marine food web. These damaging effects include decreases in reproductive capacity, growth, survival, and other reduced functions of the organisms. Although not nearly as important as light, temperature or nutrient levels, evidence indicates that ambient solar UV-B radiation is currently an important limiting ecological factor, and that even small increases of UV-B exposure could result in significant ecosystem changes.

In marine plant communities, a change in species composition, in addition to a global decrease in net production, would be a likely result of enhanced UV-B exposure. A change in community composition at the base of food webs may produce instabilities within ecosystems that likely would affect higher trophic levels. The generation time of marine phytoplankton is in the range of hours to days; whereas the potential increase in ambient levels of solar UV-B irradiance will occur in the range of decades. The question remains as to whether the gene pool within species is variable enough to adapt during this relatively gradual (relative to the generation time of the target organisms) change in exposure to UV-B radiation.

There is evidence that a decrease in column ozone abundance could diminish the near-surface season of invertebrate zooplankton populations. For some zooplankton, the time spent at or near the surface is critical for food gathering and breeding. Whether the population could endure a significant shortening of the surface season is unknown.

The direct effect of UV-B radiation on food-fish larvae closely parallels the effect on invertebrate zooplankton. Before effects of exposure to solar UV-B radiation can be predicted, information is required on seasonal abundances and vertical distributions of fish larvae, vertical mixing, and penetration of UV-B radiation into appropriate water columns. However, in one study involving anchovy larvae, a 20% increase in UV-B radiation (which would accompany a 9% depletion of total column ozone) would result in the death of about 8% of the annual larval period. This highlights the need for caution when trying to extrapolate conclusions to natural conditions when those conclusions are based on results from laboratory studies.

In many countries, marine species supply more than 50% of the dietary protein. This percentage is larger in many developing countries. Research is needed to improve our understanding of how ozone depletion could influence the world food supply derived from marine systems.

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STATUS OF SELECTED HABITATS

Tropical Forests

Tropical forests are richer in species than any other terrestrial habitat. Closed tropical forests, as mentioned above, contain at least 50 percent and perhaps 90 percent of the world's species, although they cover only 7 percent of the Earth's land surface. They include two thirds of the world's vascular plant species and about 30 percent of its terrestrial vertebrate species. Up to 96 percent of the world's arthropods may occur in tropical forests (15).

Tropical forests are important not only as the home to myriad plant and animal species, and as the source of valuable products, but also because they support diverse human cultures (16). Tropical forests also regulate vital biological, geological, and chemical cycles. As these forests decline, however, they cannot support the local climate necessary for their own survival (17). Between 1981 and 1990, an estimated 9 percent of the world's tropical forest was lost (18). Some types of tropical forests have been under especially high levels of threat. For example, 98 percent of the tropical dry forest along the Pacific Coast of Central America has disappeared (19).

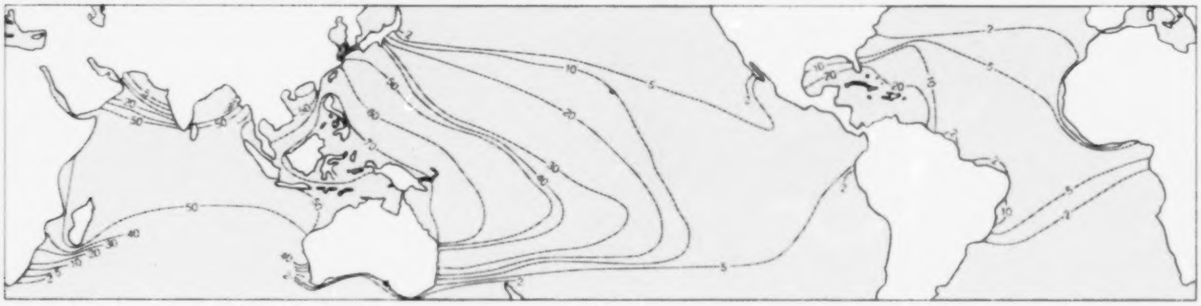
Temperate Rainforests

The loss of temperate rainforests is only beginning to receive attention. Even the existence of areas such as the temperate rainforests of the Pacific coast of the United States and Canada and in New Zealand, Tasmania, and Chile is not widely known. Historically, temperate rainforests also occupied parts of Ireland, Scotland, Iceland, and Norway, whose climates are moderated by the Gulf Stream.

These forests were never extensive. About 30 million hectares of temperate rainforest once covered an area only 4 percent of the size of today's tropical rainforest. A recent study found that only 44 percent of the temperate rainforest remains, mostly along the Pacific coast of North America (20) (21). The areas that remain are highly productive as well as diverse, playing a critical role in maintaining the health of the coastal watersheds.

The environmental and economic impacts of the loss of temperate rainforests are widespread. As these habitats decline, so do the sectors of the economy that depend on healthy forests and fisheries.

Figure 9.3 Global Distribution of Coral Reefs



Source: J.E.N. Veron, "Distribution of Reef-Building Corals," *Oceanus* (Summer 1986), p. 29

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9 Wildlife and Habitat

Coral Reefs

Coral reefs are the underwater analog of tropical forests—habitats of unparalleled biotic richness. Figure 9.3 shows that the largest number of coral genera are found in the Indian and tropical western Pacific Oceans, with fewer species in the reefs of the Caribbean and Atlantic (22). While tropical terrestrial areas have a greater number of species, marine environments contain many more phylla (a higher taxonomic classification), most of which live in coastal waters (23). Unlike the rainforests, coral reefs have fewer highly localized (endemic) species—most species that occur anywhere in the Pacific and Indian Oceans are found throughout those oceans.

Coral reefs are under severe pressure from a variety of threats. By the year 2000, approximately 1 billion people will live in coastal cities. (See Chapter 23, "Oceans and Coasts," Table 23.1.) Overfishing is depleting fish stocks; burgeoning coastal populations and their associated human, agricultural, and industrial pollution are poisoning the reefs; soil erosion from upstream agricultural lands and the destruction of forests are smothering the reefs; even tourists who visit the reefs can cause damage by walking on them. There is even speculation that global climate change is a factor in recent coral-bleaching episodes (24). (See Chapter 12, "Oceans and Coasts.")

Mediterranean Climate Areas

Five areas of the world with a Mediterranean climate—cool, wet winters and warm, dry summers—have numbers of plant species and levels of endemism that rival the tropics. These areas include the Mediterranean basin of southern Europe and North Africa, parts of California and Chile, the Cape region of South Africa (the fynbos), and southwestern Australia. For example, the fynbos of South Africa is home to 8,600 species of plants, of which two-thirds are endemic (25). Because the Mediterranean climate is so agreeable to humans, however, these regions have historically been among the most extensively disturbed in the world (26).

Islands

Because their evolution takes place in relative isolation, many islands are home to species that are found nowhere else. Remote ocean islands—such as Hawaii and Ascension—have some of the world's most unique flora: only a few of the species on these islands are found anywhere else (27). However, the fixed boundaries and endemic species of islands also put them at great risk of species extinction. Indeed, the largest number of recorded extinctions has been on oceanic islands (28). About 10 percent of the vascular plant species endemic to Hawaii are extinct and 40 percent are threatened, as are 580 endemic plant species of the Canary Islands (29).

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12 Oceans and Coasts

COASTAL HABITAT DESTRUCTION

Coastal habitats, especially wetlands, mangroves, salt marshes, and seagrasses, are rapidly being cleared for urban, industrial, and recreational growth as well as for aquaculture ponds. Coral reefs are being destroyed by pollutants, siltation from upstream erosion, use of dynamite and poison in fishing, and mining for construction materials.

Population pressures on coastal habitats are growing. New data on coastal population growth shows that about one third of the world's urban population lives within 60 kilometers of the coast. From 1980 to 2000, coastal urban populations are expected to increase by 380 million—about the 1990 population of Canada, the United States, and Mexico (28). Few countries have plans to manage development in coastal areas to offset the impact of this growth.

Measures of coastal habitat loss in developing countries are difficult to obtain. But indications are alarming. For example, in tropical countries where estimates have been calculated, the loss of mangroves averages well over 50 percent of the pre-agricultural area. (See Table 12.1.) Industrialized countries have cleared most of their coastal wetlands. The United States has lost over 50 percent of its coastal wetlands (29). The rate of loss has slowed since the mid-1970s, with the promulgation of state and federal regulations (30). In the Mediterranean, wetlands have been drained for development and for the prevention of malaria. As a result, Italy had lost over 95 percent of its historic wetlands by 1972 (31).

Coastal habitat loss is important because 90 percent of the world's marine fish catch (measured by weight) reproduces in these areas (32). Deep-water fish often feed on fish that spawn in coastal areas. The U.S. National Marine Fisheries Service estimates that 77 percent of the nation's commercial fish catch is from species that depend on estuarine wetlands for survival (reproduction, nursery areas, food production, or migration). In the Gulf of Mexico and the southeast Atlantic states, 98 percent of the commercial fish catch depends on estuaries (33). Degradation of coastal habitats can have long-term consequences for populations.

Table 12.1 Loss of Mangroves in Selected Countries Since Preagricultural Times

Location	Current sq km	Percentage Lost
Africa		
Angola	1,100	50
Cameroon	4,860	40
Côte d'Ivoire	640	60
Djibouti	90	70
Equatorial Guinea	120	60
Gabon	1,150	50
Gambia, The	510	70
Ghana	630	70
Guinea	1,200	60
Guinea-Bissau	3,150	70
Kenya	930	70
Liberia	360	70
Madagascar	1,302	40
Mozambique	2,760	60
Nigeria	12,200	50
Senegal	420	40
Sierra Leone	3,400	50
Somalia	540	70
South Africa	450	50
Tanzania	2,120	60
Zaire	1,250	50
Central America		
Guatemala	500	60
Asia		
Bangladesh	2,910	73
Cambodia	156	5
India	1,894	85
Indonesia	21,011	45
Malaysia	7,310	32
Pakistan	1,540	78
Philippines	777	61
Thailand	191	87
Viet Nam	1,468	62
Total	**76,939**	**56**

Source: World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1990-91* (Oxford University Press, New York, 1990), Table 20.4, pp. 306-307.

Coral Reef Bleaching

Of recent concern is a potential new threat to coral reefs—elevated sea temperatures that may be caused by global warming. Over the past several years, researchers in the Caribbean and eastern Pacific observed increased coral "bleaching," in which the coral's symbiotic algae, which give coral its color, abandon the coral. Without these algae, the coral will eventually die. Known causes of bleaching include pollution and sedimentation. But in some areas, researchers correlated the increased incidents of bleaching with water temperatures one or two degrees higher than normal, leading them to warn that reefs might become a casualty of global warming. Fifty scientists meeting in Miami in 1991 concluded that the incidence of bleaching has increased, much of it related to higher water temperatures, but these incidents indicate environmental stress, not global climate change. However, they warned that a 3–4° C rise in ocean temperature predicted to be caused by global warming could seriously damage corals. The scientists strongly recommended a global program of coral reef monitoring (34) (35) (36).

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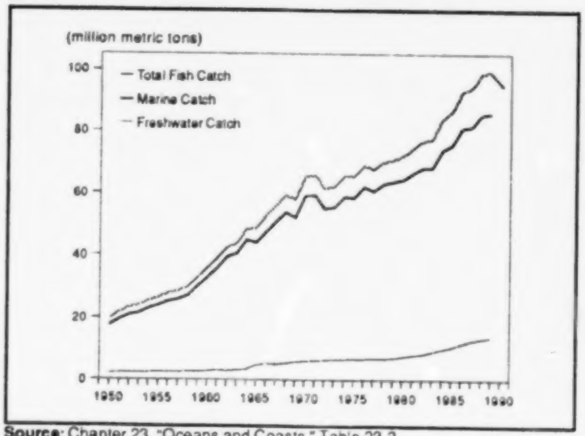
Figure 12.2 Global Fish Catch, 1950–90



Source: Chapter 23, "Oceans and Coasts," Table 23.2.
Note: 1990 figure is preliminary.

Threats to The Ocean's Surface

Although the open ocean still appears relatively clean, new studies indicate possible dangers to microscopic plants and animals that live on the ocean's surface and constitute an important part of the oceanic food web. Initial reports show that increased UV-B radiation resulting from a thinning of the ozone layer can cause reduced productivity or death in several surface-dwelling organisms, phytoplankton, zooplankton, and fish larvae, for example (37). In addition, new studies indicate that pollutants tend to concentrate in the ocean's upper layer—a critical reproductive and feeding ground for many commercially important species. Heavily trafficked seas near industrialized regions are especially vulnerable. Surface waters collected 100—200 kilometers offshore in the North Sea were contaminated with enough heavy metals and other pollutants to be toxic to the embryos of various species (38) (39).

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Montane Butterfly Distributions And The Potential Impact Of Global Warming

Stuart B. Weiss and Dennis D. Murphy

Of all human assaults on the environment, few promise to have more far-reaching effects than global warming, resulting from the "greenhouse effect." Human activities have substantially increased concentrations of carbon dioxide, methane, chlorofluorocarbons, and other trace gasses that trap heat in the atmosphere. Atmospheric scientists predict that such increases could lead to an average global temperature rise of five to six degrees Fahrenheit by the year 2050. Well-studied insect taxa, such as butterflies, offer biologists opportunities to examine the specific effects of

Stella Lake, 1000 meters below Mount Wheeler in the Snake Range. Regional warming may cause forests to ascend the slopes below the peak. Photographed in Great Basin National Park by Dennis D. Murphy.

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warming on biological diversity.

Studies of historical weather patterns and prehistoric climate shifts indicate that the distributions of plant and animal species have adjusted by hundreds of miles or thousands of feet in elevation in response to warming or cooling trends of just a few degrees. Because of their rigorous thermal requirements, butterflies as a group can be expected to respond relatively quickly to the future regional climate changes associated with global warming. Butterflies are extraordinarily sensitive to weather conditions. Development of eggs, larvae, and pupae are highly temperature dependent, and adult butterflies generally fly only during relatively sunny, calm conditions. Other factors that affect growth, reproduction, and survival of butterflies – particularly hostplant condition, availability of nectar, and abundance of natural enemies – are also greatly influenced by weather. Indeed, one year may provide ideal weather conditions for larval growth and adult reproduction, and butterfly populations may explode in numbers. The next year may bring drought or unseasonably heavy rainfall, and populations can swiftly decline. Butterflies thus should be able to tell us much about what price the greenhouse effect will exact from Earth's biological diversity.

The present distribution of butterfly species across large geographic regions shows the unmistakable fingerprint of past climate changes. Species isolated on mountaintops across the arid west and along the spine of the Appalachians, for example, reflect the most recent great climate change following the last Ice Age. Continental warming and the northward retreat of the glaciers left formerly widespread and continuous cooler habitats restricted to isolated mountaintop patches. Numerous butterfly species retreated up mountain slopes over many generations as the distributions of their larval hostplants and nectar sources shifted upward. Nowhere is this record more apparent than in the present distribution of boreal butterflies in the Great Basin of western North America.

The Great Basin makes up the vast region between the Rocky Mountains and the Sierra Nevada, and is characterized by "basin and range" topography – series of north-south trending mountain ranges separated by low lying basins, the result of stretching of the Earth's crust. The topography of the area has been metaphorically described as "an army of caterpillars marching toward Mexico." Great Basin ranges reach up to 13,000 feet, and most support isolated patches of boreal habitat surrounded by a sea of sagebrush desert and alkali flats.

The results of paleoclimatic studies suggest that boreal habitat was continuous across the Great Basin at the end of the Pleistocene. Subalpine forests existed where sagebrush now grows, basin bottoms held large lakes, and alpine vegetation was widespread across virtually all mountain ranges. About 10,000 years ago, vegetation zones began to shift upslope and northward, isolating boreal habitats.

Today, even the montane forest islands of the Great Basin are quite arid. Pinyon-juniper forest appears at about 7,500 feet. Above 9,000 feet, pinyon-juniper forests give way to subalpine forests of aspen, limber pine, bristlecone pine, and other conifers intermixed with meadows and occasional lakes. Above treeline at 10,000 to 11,000 feet, alpine plants provide a low-growing cover on the slopes up to the very highest peaks. Riparian zones slice from high glacial basins and descend along the sides of the ranges to canyon mouths near the valley floors.

The diversity of habitats produced by this dramatic topography supports nearly a hundred species of butterflies. Since post-Ice Age warming shifted habitat boundaries, local extinctions and recolonizations have shaped the present distributions of plants and animals across now-isolated forest patches. The distributions of butterfly species as well as those of mammals, birds, and plants across Great Basin mountaintops have been viewed by ecologists as similar to those on oceanic islands, where large islands that are close to mainlands tend to have more species than smaller islands farther from those sources of species. Large mountain range "islands" support more boreal habitat, hence more butterfly species, than do smaller ranges. For example, the Schell Creek / Egan Range, with 800 square miles of boreal habitat,

The ruddy copper (**Lycaena rubida**)*, a sedentary species found in sage and pinyon-juniper habitats. Photographed at Moses Lake, Washington by Edward S. Ross.*

Riparian habitat that supports many butterfly species along Timber Creek in the Schell Creek Range of Nevada. Photograph by Dennis D. Murphy.

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supports 83 butterfly species, while the nearby White Pine Range, with just 250 square miles of boreal habitat, supports only 52 species.

The capacity of each butterfly species to disperse affects its presence in habitat areas of various sizes. Highly vagile species, such as the western tiger swallowtail and Weidemeyer's admiral, freely move among mountain ranges and are found in ranges of all sizes. Vagile butterfly species readily colonize empty habitats, and can provide individuals to rescue small, isolated populations. In contrast, the most sedentary species, such as Edith's checkerspot and many species of blues and coppers, do not occur as often in smaller mountain ranges. Sedentary species rarely cross the lowland desert, and local extinctions are not offset by recolonization or by the rescue effect. As such, large boreal habitat islands have greater numbers of sedentary butterfly species than do small islands.

The relationships among habitat area, species distributions, and dispersal abilities can be used to predict or anticipate the effects of regional warming on the butterfly fauna of the Great Basin. The concept used is relatively simple: for every five-degree Fahrenheit rise in temperature, climate belts ascend mountain ranges approximately 1,500 feet. (Five degrees Fahrenheit is the temperature increase projected for about the year 2050.) With a five-degree rise in temperature, the lower limit of the pinyon-juniper forest will ascend from 7,500 feet to about 9,000 feet, with a concomitant reduction in area of that forest type. Similarly, each successive habitat belt will move 1,500 feet upslope. The boreal forests and alpine zones on some mountaintops may actually disappear.

Under a five-degree warming scenario, boreal habitat in the Great Basin would be reduced by two-thirds or more. Boreal habitat areas on the largest mountain ranges (400 to 1000 square miles or greater) would be reduced to the extent of boreal habitat on moderate-size ranges today (100 to 250 square miles). With these reductions in habitat areas, the loss of butterfly species from each range would average about 25 percent – so that the largest ranges, presently supporting 80 or more butterfly species, could be predicted to lose about 20 of their species, and moderate-sized ranges supporting 50 species would lose 10 to 15 species. Nevada's newly established Great Basin National Park, in the spectacular southern Snake Range near the Utah border, would experience a reduction of its boreal habitat area of more than one half, and the number of butterfly species would drop from 74 to about 55. Plant species richness would drop from more than 300 species in the same park area to about 250 species. And the already depauperate small mammal fauna (just 10 species) could be reduced to five or six species.

Why will so many butterfly species disappear from various mountain ranges? The reasons are diverse. Perennial water is an important butterfly resource, and would be far scarcer in a warmer climate. Hostplants and nectar sources may disappear as their habitats dry out and their growing seasons shorten in the new warmer climate. While hostplants may follow ascending climate zones, topographic microsites that favor timely development of immature life stages of butterflies may not be present in new higher elevation habitats.

If the Great Basin is going to become warmer, should we expect to see butterflies from biologically rich Arizona and northern Mexico become Nevada residents? Perhaps some. But the plants on which most southern butterfly species depend cannot migrate as readily as the butterflies, and will not be able to track rapidly shifting climate zones. Geographic features such as the Grand Canyon would pose virtually insurmountable barriers to dispersal of many species. The time scale of global warming, on the order of decades, will be far more rapid than comparable climatic shifts in the past, which took place over centuries and millenia.

We have not yet tried to project which particular species would be most prone to extinction under these circumstances, but several criteria should be examined in detail. Habitat specificity, hostplant specialization, rigorous thermal requirements, adult butterfly vagility, and a number of other factors are important variables in the ability of a species to adapt to climate change. Identifying the subset of species absent from all but the largest ranges could generate a first-cut list of species that would be at most immediate risk of extinction.

The loss of an average of 25 percent of butterfly species from Great Basin mountain ranges is but one example of the loss of biological diversity that will accompany global warming. And this example may be conservative, because many of the butterflies of the Great Basin are already relatively well adapted to warm and dry conditions. The projected global warming, expected to happen 10 to 100 times more quickly than previous climate changes, may have even more serious consequences for species that cannot adapt or adjust their distributions as quickly as necessary. Studies of life history characteristics and present and past distributions of butterflies may help us predict how, when, and where particular species or populations will be endangered by dramatic climate changes.

Regardless of the many ways in which individual species are affected, butterflies as a group will likely prove to be particularly sensitive indicators of the effects of global warming. By allowing us to monitor regional biological diversity, butterflies may perform a valuable role as "canaries in the coal mine" – if, of course, we are intelligent enough to interpret their message and to implement the social changes necessary to save them.

Stuart B. Weiss and Dennis D. Murphy are research biologists in the Center for Conservation Biology at Stanford University, where they have collaborated on numerous studies on the ecology of butterfly populations. This article is adapted from their chapter in the Consequences of the Greenhouse Effect for Biological Diversity, *edited by Thomas Lovejoy and Robert Peters and soon to be published by Yale University Press.*

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Plants

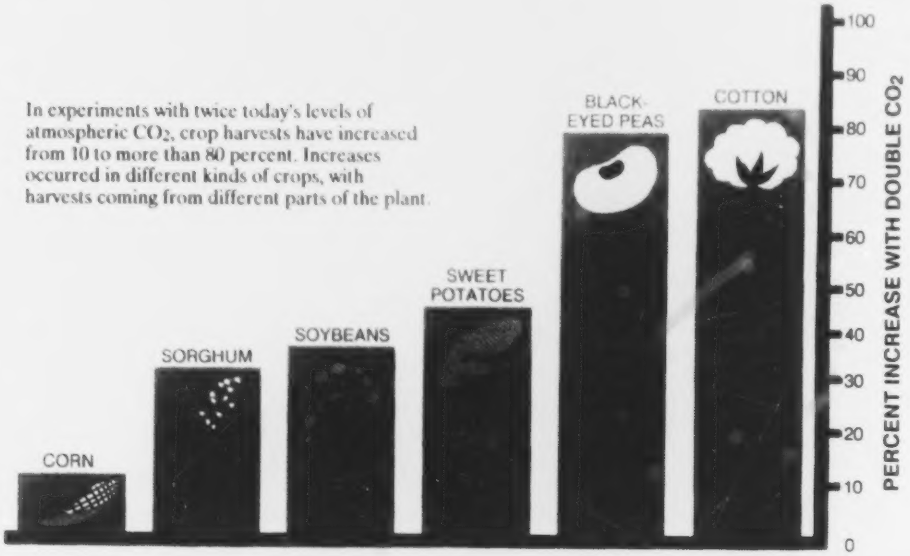
12. How is increasing atmospheric CO_2 likely to affect plants--and hence agriculture, forests, and water resources?

CO_2 fertilizes plants. In experiments, increased atmospheric CO_2 produces two major effects: it stimulates growth, and it improves efficiency in water use. If other conditions are favorable, these responses to higher levels of atmospheric CO_2 may help farmers, foresters, and water managers cope productively with changing climate conditions.

In laboratory experiments with crops, higher concentrations of atmospheric CO_2 increase harvests. Experiments jointly sponsored by the Departments of Energy and Agriculture show that exposing plants to twice the concentration of CO_2 found in today's atmosphere produces dramatic results. Except for corn, whose yield rose by 10 percent, harvests for all the crops studied increased from 30 to more than 80 percent. Harvests studied come from different parts of the plants--stems, leaves, or seeds, for example--so different kinds of crops all appear to benefit from increased levels of CO_2.

The link between increased atmospheric CO_2 and increased growth is photosynthesis. Through photosynthesis, plants assimilate CO_2 from the atmosphere and convert it into food and fiber. Thanks to this process, plants are the foundation of Earth's life support system.

Laboratory experiments with increased atmospheric CO_2 also show improved



In experiments with twice today's levels of atmospheric CO_2, crop harvests have increased from 10 to more than 80 percent. Increases occurred in different kinds of crops, with harvests coming from different parts of the plant.

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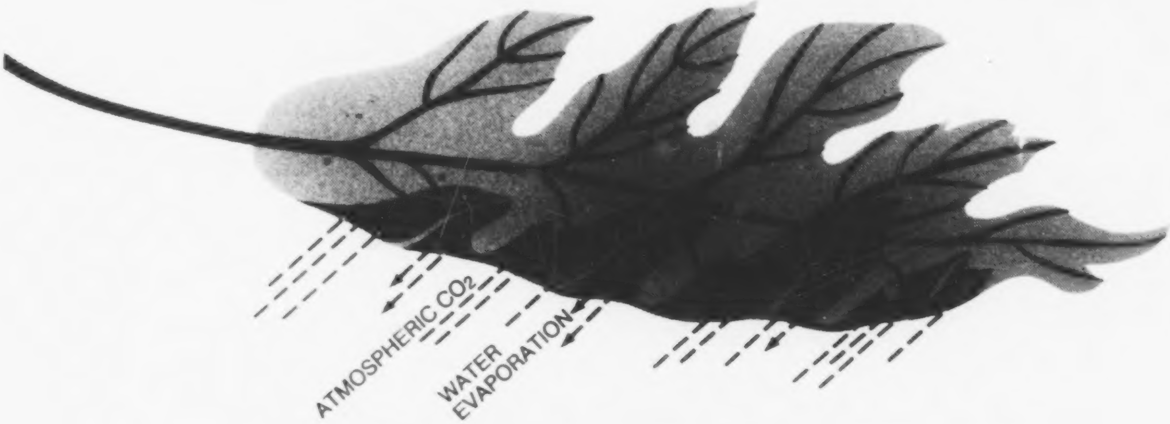


Increasing atmospheric CO_2 may help plants cope with drought, thanks to stomata on leaves, which resemble pores in human skin. When stomata open to take in atmospheric CO_2, they also release water vapor. In experiments with abundant CO_2, stomata are less open than normal, so leaves lose less water vapor and plants need less water.

"water use efficiency." CO_2 from the atmosphere enters plants through small pores in the leaves called stomata. While stomata are open to take in CO_2, they also release water vapor into the atmosphere. When CO_2 is abundant, however, stomata are less open, and less vapor loss occurs, producing the increased water use efficiency. If this process holds for outdoor field conditions, crops would require less irrigation and would be more likely to survive drought. In addition, with stomata less open, plants may be less vulnerable to airborne pollution.

Plant responses to higher levels of atmospheric CO_2 have significant--and too little recognized--implications for agriculture, forestry, and water management. These activities are important to human welfare, and they merit balanced consideration. Unfortunately, public attention has generally ignored the implications of plant responses to CO_2 and focused almost entirely on the impacts of possible climate shifts, sometimes training the spotlight on only the most alarming possibilities.

For example, citizens and legislators react with understandable anxiety to scenarios projecting climate conditions changing abruptly in the Midwestern United States and the corn and wheat belts migrating forthwith into Canada. Even with respect to climate, this speculation is misleading. Estimates of future conditions in a given region are uncertain, as the answers to Questions 7 and 8 observed. Not all climate models predict drying in the Midwest.

Visions of a vanishing farm belt also ignore crop response to CO_2. If increasing atmospheric CO_2 stimulates growth and water use efficiency, possibly offsetting potential loss of rainfall, crops may survive and even thrive under changed climate conditions. Finally, dire scenarios dismiss human resourcefulness. While heat, drought, and similar extremes certainly inflict hardship, over the long term people often become able to make an enterprise productive, despite adverse circumstances. Farmers now grow crops such as winter red wheat, for example, under conditions that were very inhospitable a few years ago. As agricultural research has developed crops that succeed under present conditions, it can also breed strains to flourish under different circumstances. Meanwhile, farmers will continue to exercise ingenuity and cultivate crops that meet economic requirements and satisfy market demand.

Potential shifts in agriculture have touched off more anxiety than possible changes in water resources, but the effects on water supplies may be more important. Water resources will also depend on plant responses to increasing atmospheric CO_2, as well as on changing climate. Again, climate is the obvious influence, because rainfall immediately affects the amount of water available, and future rainfall will probably increase in some places and decrease in others. Other climate factors like air temperature and cloudiness also help determine how much evaporation occurs and hence how much water remains in soils, lakes, and reservoirs, for instance. At the same time, as atmospheric CO_2 rises, one possibility is a decrease in demands on the water supply, thanks to improvements in plant water use efficiency. If agricultural irrigation required less water as a result, for example, more water could be available for other uses.

Current research will expand knowledge of how agriculture, forests, and water resources will respond to changing conditions. The United States Geological Survey, for example, is undertaking intensive study of an entire river basin, including the ecology of the region. By gathering and analyzing data for a complete watershed, scientists intend to strengthen water resource models, enabling them to predict the consequences of changing conditions in climate and vegetation.

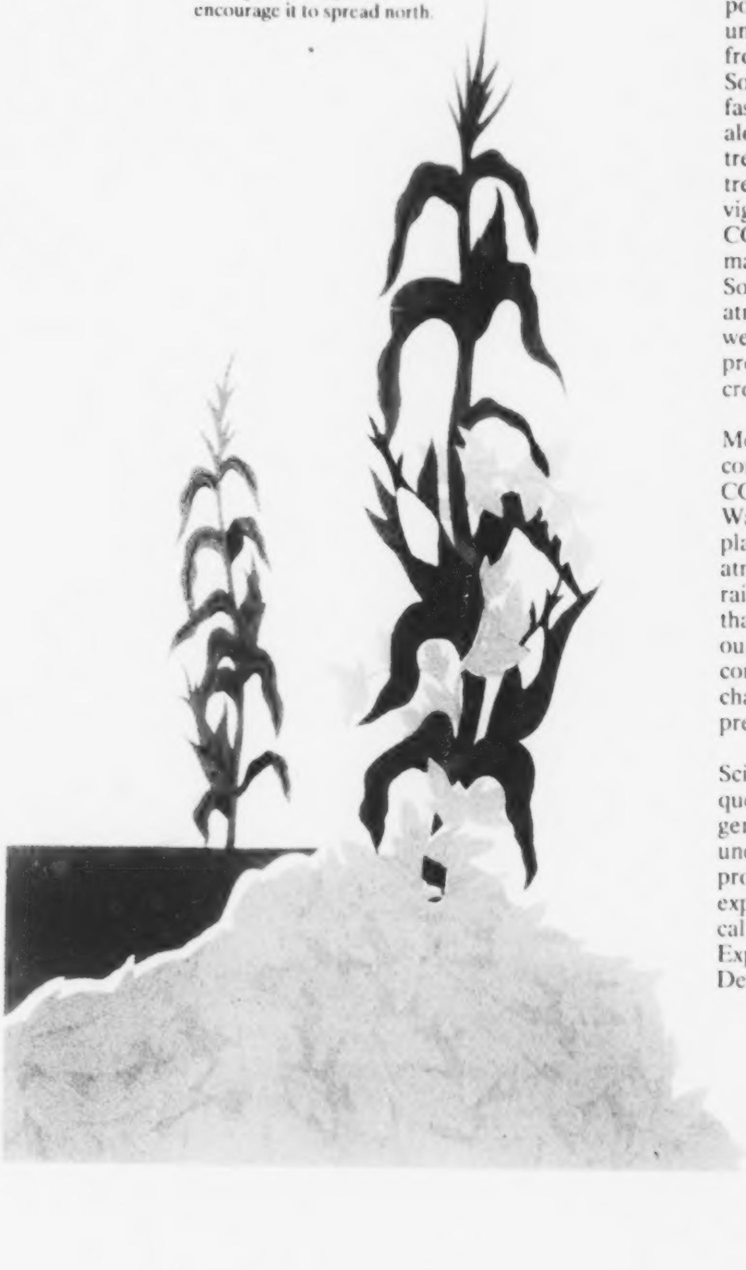
13. How will scientists learn more about plant response to increasing atmospheric CO_2?

While scientists know that elevated atmospheric CO_2 stimulates plant growth and improves water use efficiency under controlled conditions, they still have much to learn, especially about potential responses of natural plant communities. They need to develop new tools to conduct experiments and integrate findings. Even for crops, they still have many questions to explore.

Will plants sustain their present nutritional level? If plants grow larger in response to rising concentrations of atmospheric CO_2, carbohydrate content may increase, upsetting the present balance of carbohydrates and protein. One experiment with insects that feed on soybean leaves suggested such loss of nutrition. When soybeans grew under conditions of elevated CO_2, larvae of the soybean looper maintained their growth, but ate 25 percent more leaves than they do now.

Although insect leaf consumption may seem irrelevant to human nutrition, the experiment may have implications for grazing animals. Cattle and sheep, for example, depend on a diet of leaves and provide one source of human food. The experiment suggests broader questions, too, about the future

Like crops, weeds may also thrive on increasing atmospheric CO_2. In experiments with twice today's level of atmospheric CO_2, kudzu grew vigorously. This vine now grows prolifically in the Southern United States, choking most other plants. Increasing atmospheric CO_2 could encourage it to spread north.



nutritional quality of grains, fruits, and vegetables that contribute directly to human diet.

Will weeds respond as vigorously as crops to increased atmospheric CO_2? Again, experiments support this possibility. Kudzu, for example, thrives under elevated levels of CO_2. Imported from Japan to control erosion in the Southern United States, this fast-growing vine now grows prolifically along roadsides, in fields, and over treetops, choking other plants and trees. In experiments, it responds vigorously to increased atmospheric CO_2, suggesting that in the future it may spread considerably beyond the South. Greater concentrations of atmospheric CO_2, in other words, could well strengthen the chances of weeds prevailing in their competition with crops.

Most important, how will the combination of increased atmospheric CO_2 and changed climate affect crops? Warmer temperatures could affect how plants respond to increased atmospheric CO_2, for example. If rainfall increases or decreases as well, that too would no doubt affect outcomes. The potential effects of combining these factors present a challenge for researchers attempting to predict future plant response.

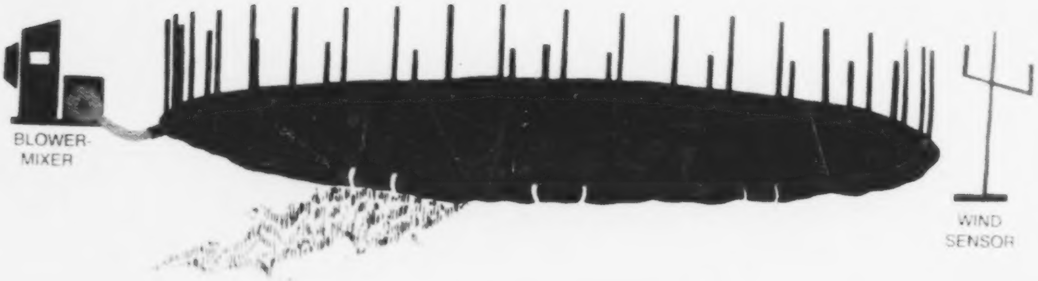
Scientists are investigating these questions studying new crops, and generally improving their understanding of fundamental plant processes. A number of their experiments will use a new technique called "FACE"--Free-Air CO_2 Exposure--developed in the Departments of Energy and

Agriculture research. This method exposes vegetation to elevated levels of CO_2 in the open air, without otherwise disturbing natural conditions. It allows researchers to determine whether data obtained in laboratories and greenhouses accurately represent plant response under normal field conditions. FACE has the additional advantage of enabling scientists to study not just crops, but natural vegetation, too.

Plants grown for food are not the only species important to our welfare. Natural vegetation in forests and grasslands also matters to the economy and to ecology, recreation, and aesthetics. Scientists know relatively little about how natural communities of vegetation will respond to increased atmospheric CO_2 and different climate conditions, so this entire area will also be a field for research.

Finally, scientists are developing models to predict how plants will respond, individually and in communities, to changing conditions. Researchers cannot perform experiments on all species, and all combinations of species, to see how they will react to increased CO_2. Although current models require further development and testing, improved models could examine how variations in key conditions--CO_2, temperature, and rainfall, for instance--would affect plant survival, growth, yield, and water use efficiency.

Scientists are designing new techniques for studying both cultivated and wild plants. FACE--Free-Air CO_2 Exposure--blows CO_2 into the experimental area, but leaves other conditions undisturbed, so researchers can measure plant response to increased atmospheric CO_2 in a natural setting.



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GLOBAL CLIMATE CHANGE AND AGRICULTURE
A SUMMARY

by Susan C. Whitmore
Bureau of Mines
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The atmospheric accumulation of carbon dioxide (CO_2) and other gases from burning fossil fuels and other human activities may be enhancing the atmosphere's capacity to trap infrared radiation emitted by the Earth. The trapping of radiation warms the Earth's surface in a process similar to that which occurs in a greenhouse, hence the often used term "greenhouse effect." If increased warming were to occur, climate changes could cause serious consequences for human activities and resources in areas such as energy production and use, climatic patterns, coastal land use, agriculture, forestry, and water supplies, and also could produce population shifts. Although causal relationships between long-term climate changes and recent weather trends have not yet been established, such conditions have focused public attention on potential climate changes and the need for better understanding of climate.

WHAT IS THE "GREENHOUSE EFFECT"?

A blanket of air envelopes the Earth and moderates the Earth's temperature. This blanket is made up of abundant or major gases, such as nitrogen and oxygen, and minor gases, such as water vapor and carbon dioxide. The atmosphere controls the Earth's temperature because some of the minor atmospheric gases, including those of natural origin and some produced by human activities, are relatively transparent to incoming short-wavelength sunlight, but are opaque to longer wavelength infrared radiation arising from the Earth's surface and from the lower atmosphere. This mechanism of control has been termed the "greenhouse effect," since it is similar to the processes which occur in a greenhouse where the glass envelope acts like a compressed atmosphere, passing and absorbing radiation of different wavelengths, with the temperature inside the greenhouse rising to a level above that of the surroundings.

On Earth, sunlight not reflected by clouds or absorbed by the atmosphere is either absorbed by the Earth's surface or reflected back to space. The absorbed energy warms the surface of the Earth, which acts as a radiator, re-emitting energy upward into the atmosphere.

The energy that is absorbed and re-radiated at the surface of the Earth and at the various levels in the atmosphere maintains the Earth at a life-sustaining temperature that is warmer than it would be if there were no intervening atmosphere. Without atmospheric "greenhouse gases" and the resulting "greenhouse effect" the Earth's average surface temperature might be as low as -20 degrees Celsius (C) (-4 degrees Fahrenheit (F)).[6]

Natural processes contribute "greenhouse gases" to the atmosphere. However, many people are concerned that human activities are increasing the atmospheric concentrations of carbon dioxide (CO_2) and other "greenhouse gases" which, given no other mitigating effects, will lead to more efficient absorption of energy by the atmosphere, producing global warming and its accompanying effects.

A seemingly small change in overall atmospheric temperature can have a large effect on the Earth. The Earth has not been more than 1 to 2 degrees C (1.8 to 3.6 degrees F) warmer during the 10,000-year era of human civilization. The previous ice age, in which glaciers stretched from present day New York to Chicago, was only 5 degrees C (9 degrees F) cooler than now.[6]

WHAT ARE "GREENHOUSE GASES"?

The four most important "greenhouse gases," whose atmospheric concentrations can be influenced by human activities, are carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons.

- Carbon dioxide (CO_2) occurs naturally in the atmosphere, and plays an important role in almost living organisms. Animals, including humans, exhale it while plants take it in, using the carbon it contains to manufacture carbohydrates. There has been a 25-percent increase in CO_2 in the last 100 years.[6] The burning of fossil fuels (coal and oil) and deforestation are the primary contributors of CO_2 from human activity.

- Methane is the major constituent of natural gas and is also produced from many biological decay processes (in the digestive system of ruminant animals such as cattle or deer, and in rice fields and wetlands). Rice production is believed to be the primary contributor of methane from human activity.[8] There has been a 100-percent increase in methane in the past 100 years.[6]

- Nitrous oxide (laughing gas) is produced from microbial action in the soil. Of the nitrous oxide released each year, about 10 percent is due to the use of fertilizer.[9] Natural microbial activity; the spread of agriculture; and the burning of forest vegetation, crop residues, and fossil fuels account for most of the rest.

- Chlorofluorocarbons (CFCs) are used as the cooling fluids in refrigeration, as propellants in aerosols, as solvents, and as foam-blowing agents in the production of plastics. Unlike the other greenhouse gases, CFCs are not produced naturally and their presence in the atmosphere is due solely to industrial production. Virtually all CFCs produced eventually end up in the atmosphere and are very long-lived.[9]

IS THE EARTH WARMING?

Whether global warming due to an accelerated "greenhouse effect" is actually occurring is controversial.

- James E. Hansen, Directory of the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies, New York City, and his colleagues analyzed temperature records dating from 1880 to 1985. Their results indicate a global warming of 0.5 to 0.7 degrees C (0.9 to 1.26 degrees F) in the past century.[1]

- Thomas M.L. Wigley and his colleagues, from the University of East Anglia in England, also have shown an increase in average global temperature.[3]

- Climatologists Thomas Karl, Kirby Hanson, and George Maul at the National Oceanic and Atmospheric Administration (NOAA) completed a study that shows no overall increase in annual temperature for the contiguous U.S. from 1895 to 1987.[2]

- An exhaustive study of worldwide ocean temperatures since 1850 by MIT climatologists Reginald Newell and his colleagues concludes that, "There appears to have been little or no global warming over the past century."[5]

- The U.S. National Academy of Sciences concludes that, based on model predictions, a 1.5 to 4.5 degrees C (2.7 to 8.1 degrees F) global warming may occur in the next century.[6]

- The seven warmest years recorded in the past 100 years (based on average global temperatures) were 1990, 1988, 1987, 1983, 1981, 1980, and 1986, in that order.

POTENTIAL EFFECTS OF GLOBAL CLIMATE CHANGE

Estimates of global warming by the middle of the 21st century vary from 2 to 9 degrees C (3.6 to 16.2 degrees F).[4] If a significant temperature rise were to occur, important changes might be seen on the Earth's surface. Global warming could affect energy production and use, climatic patterns, agriculture, forestry, and water resources. It could lead to rising sea levels and the flooding of coastal regions.

While a direct relationship between long-term trends and recent warm weather has not been established, such conditions have focused public attention on potential climate change and its resulting effects.

The Environmental Protection Agency drafted a report entitled *The Potential Effects of Global Climate Change on the United States* in which they speculated about the following possible effects of climate change on agriculture and forestry.[7]

Potential Effects of Global Climate Change on Agriculture

Agriculture is a critical U.S. industry, providing food for the Nation's population and as much as $43.6 billion in exports for the Nation's trade balance. In 1985 total farm assets were $771 billion, and food and fiber crops represented 17.5 percent of the total gross national product.[7] Wheat, corn, soybeans, cotton, fruits and vegetables, and livestock are among the most important U.S. agricultural commodities.

Although climate change is not likely to threaten U.S. food supplies, it may:

- Reduce or increase average yields of corn, soybeans, and wheat, both rainfed and irrigated. Increased yields may occur in northern latitudes where warmer conditions would provide a longer frost-free growing season. Decreased yields may occur in mid-latitudes primarily from higher temperatures which shorten a crop's life cycle.

- Increase the yields of corn, soybean, and wheat since increased atmospheric CO_2 may increase plant growth.

- Result in a northward shift in cultivated land, causing significant regional dislocations in agriculture with associated impacts on regional economies.

- Shift rainfall patterns, which might expand crop irrigation requirements in certain regions and, hence, increase competition for regional water supplies and increase surface and ground water pollution.

- Change the ranges and populations of agricultural pests. These effects could change pest control requirements.

- Result in sea level rise and the flooding of near-coastal agricultural lands.

Potential Effects of Global Climate Change on Forestry

Forests occupy 33 percent of the U.S. land area and exist in all 50 states. In total, they occupy 738 million acres and are rich in resources such as water and wildlife. Global warming could affect the forests of the U.S. significantly. Changes could be apparent in 30 to 80 years, depending on the region, a site's quality, and the rate of climate change.

- The southern ranges of many forest species in the eastern United States could experience dieback of several hundred miles depending on the extent of temperature changes and drying soils. This dieback could result in a serious loss of productivity, depending on how dry the soils become.

- The potential northern range of forest species in the eastern United States could shift northward as much as 400 miles over the next century. Productivity could increase along the norther limits of some eastern species.

- If elevated CO_2 concentrations substantially increase tree growth through an increase in photosynthesis and efficiency of water use, the southern declines could be alleviated.

- If climate stabilizes, forests might eventually regain a generally healthy status over a period of several centuries. In the meantime, declining forests could be subject to increased fires, pest attacks, disease outbreaks, wind damage, and air pollution.

- Additional possible impacts of changes in forests include reductions in biotic diversity, increased soil runoff and erosion, reduced aquifer recharge, and changes in wildlife habitat and recreation.

Many of these speculations about the possible effects of global climate change are controversial. For instance, the influence of an accelerated global climate change on rainfall patterns is uncertain. Some global models predict reduced rainfall, other increased rainfall, and still other only a change in the pattern of rainfall.

Because of the global implications of this problem, scientists, diplomáts, and policymakers are combining efforts to achieve consensus on an eventual agreement concerning global warming.

A major component of international cooperation is the Intergovernmental Panel on Climate Change (IPCC) which was set up in 1987 by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) to asses the scientific information "related to the various components of the climate change issue" and formulate "response strategies for the management of the climate change issues" (see *Chronology of Global Climate Change*).

WHAT CAN YOU DO?

- Become knowledgeable about the issues involved in global climate change. The bibliographies and the directory of organizations included in this Global Change Packet will lead you to additional information. Specifically, the pathfinder lists publications that discuss global climate change and agriculture.

- If you are concerned about how to counteract human activities which contribute to production of "greenhouse gases," specific suggestions are given in:

  Bates, Albert K. *Climate in Crisis: The Greenhouse and What You Can Do About It.* Summertown, TN: Book Pub. Co., 1989. 304 p.

  Earth Works Group. *50 Simple Things You Can Do to Save the Earth.* Berkeley, CA:

Earth Works Press, 1989. 96 p.

Hollender, Jeffrey. *How to Make the World a Better Place: A Guide to Doing Good.* NY: William Morrow, 1990. 303 p.

MacEachern, Diane. *Save Our Planet: 750 Everyday Ways You Can Help Clean Up the Earth.* Washington, DC: National Wildlife Federation, 1990. 210 p.

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1. Hansen, James and Sergej Lebedeff. Global Trends of Measured Surface Air Temperature. *Journal of Geophysical Research*, p. 13, 345-13, 372, November 20, 1987.
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3. Jones, P.O., T.M.L. Wigley, and P.B. Wright. Global Temperature Variations Between 1861 and 1984. *Nature*, p. 430-434, July 1986.
4. Morrison, Robert E. *Global Climate Change* (CRS Issue Brief: Major Tracking Issue). Washington, D.C.: The Library of Congress, Congressional Research Service, January 5, 1990. 20 p. (available to members of Congress only)
5. Newell, Reginald. Earth's Climatic History. *Technology Review*, p. 30-45, December 1974.
6. Schneider, Stephen H. Cooling It. *World Monitor*, p. 30-38, July 1990.
7. Smith, Joel B. and Dennis A. Tirpak. *The Potential Effects of Global Climate Change on the United States: Draft Report to Congress.* Washington, DC: Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Office of Research and Development, October 1988.
8. Strommen, Norton D. *A Global Perspective on Weather Trends - The Most Unpredictable & Least Controllable Nature Resource.* Paper presented at the World Food Production Symposium, November 6, 1989, in Rio de Janeiro, Brazil.
9. United National Environment Programme. *The Greenhouse Gases.* Nairobi Kenya: UNEP, 1987. 40 p.

Reprinted with permission from *Global Climate - Past, Present, and Future,* S. Henderson, et al (Eds.), EPA Report No. EPA/600/R-93/126, pp. 13-18, U.S. Environmental Protection Agency, Office of research and Development, Washington, DC.

What Is the Relationship Between Climates and Terrestrial Biomes?

ACTIVITY 3

Lesson Focus:

What are biomes and how do they interact with climate?

Objective:

The student will be able to:

1. Define the term "biome".
2. Locate and describe the characteristics of the major terrestrial biomes of the world.
3. Compare a variety of biomes throughout the world.
4. Describe the adaptive characteristics needed by plants and animals in different biomes.
5. Summarize the relationship between climates and biomes.

Time:

2 days

Grade Level:

8 –10

Key Concepts:

Current climate, geographical regions, environmental adaptation

Definitions of Terms:

Biome: A geographic area characterized by specific kinds of plants and animals.

Adaption: An inherited trait that increases an organism's chance of survival in a particular environment.

Background:

Biomes refer to broad geographic regions that are characterized by relatively similar climate, topography, flora, and fauna. These biomes are generally identified by their dominant plant life (e.g., grasslands, forests). Biomes seldom have distinct boundaries. There are many different classifications of the world's biomes in varying degrees of detail. Generally they all include the tundra, desert, forest, grasslands, or some subset of these. Many biology textbooks have maps of the world's biomes. Any of these could be used for this activity.

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ACTIVITY 3

As with any attempt at regionalization, biomes share key characteristics (they are more similar than dissimilar), however they are not homogeneous. For example, a polar biome is characterized by much lower temperatures than a tropical forest biome. But even within the polar biome, one can expect a range of temperatures (generally –40 °C to –4 °C). If you were high above the ground in a jet you could identify areas that would appear to be deserts, forests, or grasslands. You may find it difficult to determine where one biome begins and another ends as the two merge into areas of transition.

Organisms that live in any given biome have features that have allowed them to adapt to the environment of that biome. Each biome has plants and animals that are uniquely qualified to survive there. Keep in mind there are species that can survive in a number of different biomes.

Activity:

Using maps and other reference materials, students will demonstrate their understanding of the relationship between biomes and climate. The students will also identify the adaptive characteristics or features of plants and animals representative of the different biomes.

Materials:

- Biome maps (from textbooks or other sources)
- Biome Characteristic Chart (attached)
- World atlas
- Large sheets of butcher paper
- Felt pens

Procedure:

1. Based on the number of biomes on the map you choose to use (usually seven or eight), divide the class into small discussion groups and assign each group a different biome to explore. Distribute a Biome Characteristic Chart to each student.
2. Have each biome group gather data from the world atlas (or similar sources) about their biome using the Biome Characteristic Chart as a guide. This task will require estimating and generalizing. For example, the polar biome group will find a range of temperatures in their defined area. They should record the range on the Biome Characteristic Chart. Each group should complete the chart for their biome.
3. Each group should list the key characteristics of their biome on a sheet of paper and hang the papers on the chalk or bulletin board. A spokesperson for each group can share their information with the class.
4. After all the biome characteristics have been covered, students should be encouraged to discuss their findings through open-ended questions. Examples of questions:
   a. What would the seasonal weather be like in the different biomes?
   b. Do different animals live in different biomes depending on the time of year (consider migratory bird species)? How can they survive in such different environments?
   c. Why are humans able to live in all biomes?

d. In what ways are humans changing biomes?

e. Which biome do you currently live in? What do you like/dislike about it?

Student Learning Portfolio:

1. List of biomes and their characteristics.
2. Written answers to discussion questions.

Extensions:

Have students pick a characteristic plant or animal from any biome and research its life history characteristics. Delineate the plant or animal's range on a large world map. Is it only found in one biome or does its range include more than one biome?

Notes:

What Is the Relationship Between Climates and Terrestrial Biomes?

STUDENT GUIDE—ACTIVITY 3

Definitions of Terms:

Biome: A geographic area characterized by specific kinds of plants and animals.

Adaption: An inherited trait that increases an organism's chance of survival in a particular environment.

Activity:

Using maps and other reference materials, you will explore the relationship between biomes and climate. You will identify the adaptive characteristics or features of plants and animals representative of the different biomes.

Materials:

- Biome maps (from your textbook)
- Biome Characteristic Chart
- World atlas
- Large sheets of butcher paper
- Felt pens

Procedure:

1. Your class will be divided into small discussion groups. Each group will be assigned a biome.
2. With your biome group, gather data from the sources your teacher has provided and fill in the Biome Characteristic Chart for your assigned biome.
3. Your biome group should list the key characteristics of your biome on a sheet of paper. Hang the paper on a chalk or bulletin board. A spokesperson for your biome group can share the key characteristics of your biome with the rest of the class.❑

Notes:

STUDENTGUIDE—ACTIVITY 3

Biome Characteristic Chart: For each biome, list the following.

1. Average yearly temperature range:

2. Average yearly precipitation:

3. Soil characteristics:

4. Characteristic vegetation:

5. Characteristic animals:

6. Adaptive features of plants to survive in this biome:

7. Adaptive features of animals to survive in this biome:

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How Might Elevated CO_2 Affect Plants?

ACTIVITY 13

Lesson Focus:

Plants use CO_2 as a nutrient, absorbing it through the process of photosynthesis. Do plants respond to increasing CO_2? If so, how do they respond?

Objective:

The student will be able to:

1. Conduct an experiment on the effect of elevated CO_2 on plants.
2. Explain the use of a "control" in scientific experimentation.
3. Analyze observed data and record results.
4. Form reasoned opinions about the relationships between CO_2, plants, and climate change.

Time:

- 1 class period for setup
- 3–4 weeks of daily care (5 minutes a day)
- 1 class period for observation/discussion

Grade Level:

8–10

Key Concepts:

Carbon dioxide, plant growth, experimentation, data gathering

Definitions of Terms:

Photosynthesis: The process used by plants to convert atmospheric carbon dioxide (CO_2) into sugars utilizing energy derived from sunlight. The sugars can be further converted into organic compounds needed for plant growth or can be used as an energy source for the plant.

Carbon Sequestering: The act of removing carbon from the atmosphere and storing it for long periods of time. Long-lived forest trees are natural carbon sequesterers in that they use atmospheric CO_2 to build woody tissue. That tissue will retain the carbon as long as the tree is alive (for hundreds of years in certain species). In contrast, annual plants (like wheat or corn) will only store carbon for one growing season, then release it as they die and decay at the end of the season.

Background:

Plants depend on a steady supply of atmospheric CO_2 for survival. Through the process of photosynthesis, plants take CO_2 out of the air and turn it into sugars, starches, and other organic molecules. Many plants benefit from increasing CO_2, increasing growth rates, size, and yield in response, as long as there is sufficient light, water, and other nutrients to support the growth. Different species respond differently, with some species responding far less than others. The projected increases in atmospheric CO_2 over the next century may double the average global concentration from approximately 350 ppm (parts per million) (in 1990) to 700 ppm (by the end of the next century). Recent experiments have suggested that many plants will likely respond to such an increase with increased growth, if all other environmental conditions remain the same. This exercise is designed to demonstrate the principle that increased CO_2 can act to enhance plant growth. Because the plant response should be rapid and obvious, and cannot depend on elaborate CO_2 control or monitoring equipment, we will use human breath (which contains approximately 10,000 ppm CO_2) as our source of extra CO_2. To enrich the CO_2 environment around plants, we will grow them in small enclosed chambers and add human breath to the chambers on a regular basis.

Activity:

Students will plant, care for, and observe the changes in growing plants under conditions of ambient (normal) CO_2 and increased levels of CO_2.

Materials:

For each team of two students:

- Two soda bottle "experimental chambers" (see Activity 6 page 43)
- One plastic saucer for each bottle
- Knife, scissors, tape
- Potting soil sufficient to fill the bottle bottoms
- Seeds of several different species of plants (tomato, wheat, bean, cucumber, clover, etc)
- Water-soluble plant food
- Straws
- Hand pump (often sold as balloon pumps or aspirators)

Procedure:

1. Fill the plastic bottoms with potting soil and set in the saucers. Water the soil so that it is very moist.
2. Each team should select a plant type to work with from the seeds available. Plant two seeds in each pot, and plant at least two pots, one to add CO_2 to and one with normal CO_2 to serve as a control. Leave the bottle tops off until the seedlings emerge. Make sure that each plant species is selected by two or more teams to allow conclusions to be checked between teams.
3. After 2–4 days the seedlings should emerge. Thin the seedlings to one per pot and place the bottle tops on each pot. Label one bottle "+CO_2", and the other "Normal CO_2". Set the bottles in a bright place. Once you place the bottles on the pots, the bottles will serve to trap the moisture inside, so you should be careful not to overwater the plants.
4. CO_2 Treatment: Beginning now, and for each school day for the next 3 weeks, enrich the CO_2 in the "+" bottle by blowing 10 breaths into the bottle through a straw (Figure 1). Leave the caps off of both bottles, but to reduce the extra CO_2 leakage

out of the top of the bottle cover approximately half the opening with a piece of tape. Although some air will exchange through the opening, the extra CO_2 will mostly remain in the bottle.

Control Treatment: In order to ensure that, except for the extra CO_2, both treatment groups are exposed to the same conditions, the Control group will also have air added, at the same time the extra CO_2 is put into the other group. To add air without adding additional CO_2, use the hand pump to gently pump room air into the bottle (pump approximately 25 times per bottle).

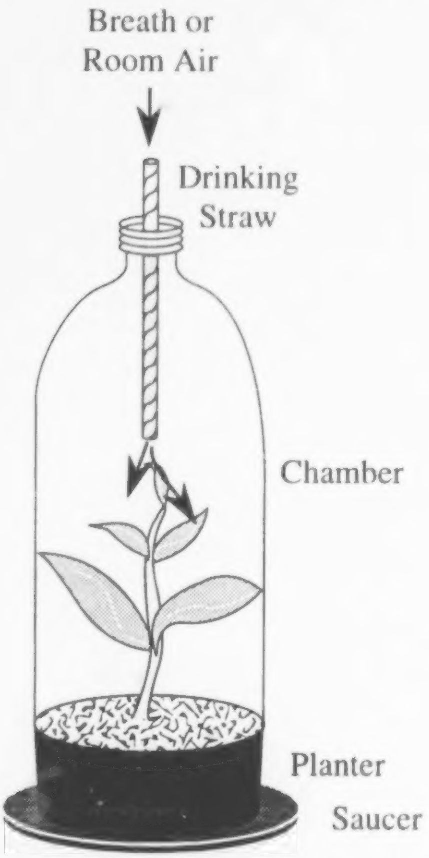

Figure 1. Completed Bottle Chamber Assembly

Remind the students not to hold the intake of the hand pump near their faces so that they don't pump their exhaled breath into the control bottles.

5. Have the students describe the experimental setup and CO_2 enrichment technique, and record observations of the plant and bottle conditions in a logbook throughout the experiment.
6. Water the plants when necessary by adding water to the saucers. Do not pour water into the top opening or remove the bottle top from the base. Water with a water-soluble plant food each time.
7. At the end of 3 weeks, remove the bottles from the bases, measure the heights, number of leaves, and any other growth parameter of interest. Each student team will record these values in their logs and share their results with the class. Be prepared for some plants responding more than others. If the responses generally seem small, it may be because other factors had limited the plant growth (e.g., There was not enough light, water, or nutrient to support good growth.) Be prepared to discuss these. As with any true experiment, there may be unexpected results.
8. Discuss the results. Consider the following questions:
   A. For the plants that grew better under high CO_2, do these results mean that they will benefit from global warming?

   They might, if all other growth conditions were favorable.

   B. What about the additional effect of changing weather (heat, drought, etc.)?

   Unfavorable weather conditions (high

temperatures, drought) would reduce the capacity of the plant to benefit from the additional CO_2, whereas conditions that might favor growth (such as warmer weather in a cold area, or more rainfall in a dry area) may enhance it.

C. If plants respond to more CO_2 by taking more in, might they take enough in to reduce the CO_2 concentration in the atmosphere?

Yes, they might, if sufficient long-lived plants such as forest trees respond to the CO_2, and if enough forests are either re-planted or protected from land-use changes.

If so, what will happen to the CO_2 when the plants die?

Decay of the plant tissue will release the CO_2 back to the atmosphere. Annual plants return their fixed carbon back to the atmosphere within a year, perennials, especially long-lived trees may hold, or sequester the carbon for many decades.)

D. If you had to select plants that would take CO_2 out of the atmosphere and hold it for extended periods, what would you select?

From the answers above, it is clear that long-lived, fast growing trees or other woody perennials would be the best selections for carbon sequestering. Scientists and policymakers are currently exploring the scientific, social, and economic factors that should be considered in beginning planetary reforestation programs to reduce CO_2 buildup.

Student Learning Portfolio:

1. Description of the experiment, observations, and final data in the student log.
2. Written summary of class results in log. Which plants responded, how did they respond, etc.
3. Written answers to question for discussion.

Extensions:

Students may try many different experiments using this bottle-exposure chamber system. They may experiment with plants not examined in class, they may try varying other conditions such as less water, less nutrients, and/or changing light levels.❑

Notes:

How Might Elevated CO_2 Affect Plants?

STUDENTGUIDE—ACTIVITY 13

Definitions of Terms:

Photosynthesis: The process used by plants to convert atmospheric carbon dioxide (CO_2) into sugars utilizing energy derived from sunlight. The sugars can be further converted into organic compounds needed for plant growth or can be used as an energy source for the plant.

Carbon Sequestering: The act of removing carbon from the atmosphere and storing it for long periods of time. Long-lived forest trees are natural carbon sequesterers in that they use atmospheric CO_2 to build woody tissue. That tissue will retain the carbon as long as the tree is alive (for hundreds of years in certain species). In contrast, annual plants (like wheat or corn) will only store carbon for one growing season, then release it as they die and decay at the end of the season.

Activity:

You will plant, care for, and observe the changes in growing plants under conditions of ambient (normal) CO_2 and elevated CO_2.

Materials:

For each team of two students:

- Two soda bottle "Experimental Chambers"
- One plastic saucer for each bottle
- Knife
- Scissors
- Tape
- Potting soil sufficient to fill the bottle bottoms
- Seeds
- Water soluble plant food
- Straws
- Hand pump

Procedure:

1. Fill the plastic bottoms with potting soil and set in the saucers. Water the soil so that it is very moist.
2. Each team should select a plant type to work with from the seeds available. Plant two seeds in each pot, and plant at least two pots, one to add CO_2 to and one with normal CO_2 to serve as a control. Leave the bottle tops off until the seedlings emerge.
3. After 2–4 days, the seedlings should emerge. Thin the seedlings to one per pot and place the bottle tops on each pot. Label one bottle "+CO_2", and the other "Normal

CO_2". Set the bottles in a bright place. Once you place the bottles on the pots, the bottles will serve to trap the moisture inside, so you should be very careful not to overwater the plants.

4. *CO_2 Treatment:* Beginning now, and for each school day for the next 3 weeks, enrich the CO_2 in the "+" bottle by blowing 10 breaths into the bottle, through a straw (Figure 1). Leave the caps off of both bottles, but to reduce the extra CO_2 leakage out of the top of the bottle cover approximately half the opening with a piece of tape. Although some air will exchange through the opening, the extra CO_2 will mostly remain in the bottle.

   Control Treatment: In order to ensure that, except for the extra CO_2, both treatment groups are exposed to the same conditions, the Control group will also have air added, at the same time the extra CO_2 is put into the other group. To add air without adding additional CO_2, use the hand pump to gently pump room air into the bottle (pump approximately 25 times per bottle).

5. Describe the experimental set-up and CO_2 enrichment technique, and record observations of the plant and bottle conditions in a logbook throughout the experiment.

6. Water the plants when necessary by adding water to the saucers. Do not pour water into the top opening or remove the bottle top from the base. Water with a water-soluble plant food each time.

7. At the end of three weeks, remove the bottles from the bases, measure the heights, number of leaves, and any other growth parameter of interest. Record the values in your logbook. Be prepared to share your results with the class.❑

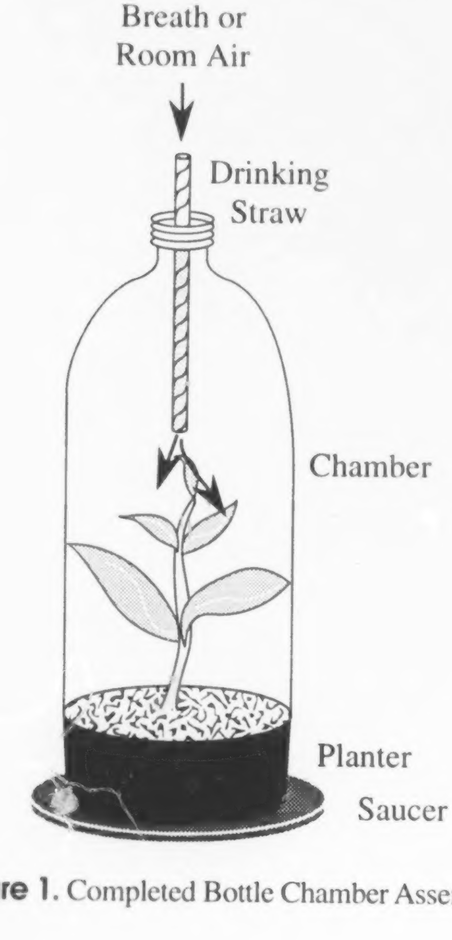

Figure 1. Completed Bottle Chamber Assembly

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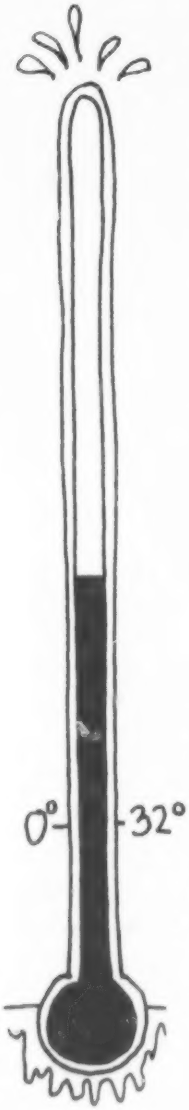
Effect of Temperature on Living Organisms

Student worksheet

Connections
- Adaptation
- Environmental factors
- Symbiosis



Background

Living organisms are sensitive to factors in their environment, such as light, heat, moisture, acidity and other abiotic (nonliving) factors. If global warming is occurring, many organisms will be affected by the increase in temperature. The activities included here are designed to demonstrate the effects of temperature on some organisms.

Although some organisms can tolerate extremely low or extremely high temperatures, most organisms survive best at moderate temperatures. Some exceptions are the bacteria and blue-green bacteria, which can survive in alpine, arctic and antarctic snow fields and others which can survive in hot springs where temperatures can exceed 130° F.

Some organisms can survive over a very wide range of temperatures, while others can live in only a very narrow temperature range. Obviously, global warming will affect the latter type of organisms more severely than the others. A further complication is that warming may promote the growth of some plants and increase production. However, these beneficial effects may be offset by increased reproduction of harmful insects, fungi and bacteria.

Source: Morholt, E., Brandwein, P. A Sourcebook for the Biological Sciences, 3rd edition, Harcourt Brace Jovanovich, 1986.

Activity 1
Effect of Temperature on Heartbeat in Daphnia

Materials: cultures of Daphnia, depression slides, petroleum jelly, aquarium water from cultures, thermometers, stopwatches, beakers, water baths, microscopes.

Procedure- Activity 1

Place small amounts of the petroleum jelly in the bottom of the well of a depression slide. Gently place one Daphnia on the jelly to hold it and cover with aquarium water. Count the number of heartbeats in 15 seconds (which may be as high as 90 times) by observing under the low power of the microscope. Vary the temperature of the water by maintaining beakers of Daphnia cultures in water baths of varying temperatures. Record the data in a table and prepare a graph of the results.

Maintaining Daphnia Cultures in the Laboratory

Cultures of Daphnia can be purchased from biological supply houses and maintained in the laboratory in battery jars of dechlorinated tap water. (Let water stand for 24-48 hours before using.) Inoculate jars with algae cultures, such as Chlorella and place in strong sunlight or under a lamp. Allow 2-3 days for the algae to multiply before adding the Daphnia to the jars. Growth can be enhanced by the addition of small amounts of mashed hard-boiled egg yolk or a suspension of yeast. Maintain temperature of the jars between 75° and 79° F.

Activity 2
Effect of Temperature on Fermentation of Yeast

Materials: yeast cultures, side arm fermentation tubes, 5% glucose solution, cotton, water baths, thermometers.

Procedure: Prepare a concentrated yeast suspension and the glucose solution. Add yeast to the glucose and fill the fermentation tubes so the side arm is completely filled. Leave the bulb partly empty and plug the opening with cotton. Place tubes in water baths of different temperatures (such as 32°C., 35°C., and 42°C. Carbon dioxide should accumulate in the side arm as fermentation occurs. Measure the length of the gas column in the side arm as a function of temperature.

Effect of Temperature on Living Organisms (Cont'd)

Student worksheet

If side arm fermentation tubes are not available, a substitute can be made by inverting a small 15 mm. vial of yeast-glucose suspension inside a large test tube, or a test tube full of yeast-glucose suspension can be inverted in a dish of the same liquid.

Activity 3
Effect of Temperature on Breathing Rate of Goldfish

Materials: goldfish, 1 beaker per goldfish, hot plates, thermometers, aquarium water

Procedure: Place aquarium water in labeled beakers and add one goldfish per beaker. Record the water temperature and the number of beats of the gill covers per minute for each fish. Place beakers on a hot plate and allow the temperature of the water to rise slowly, to a maximum of 5°F. After each 1°F. rise in temperature, record the number of gill beats per minute. Pool data from all the goldfish and graph. As the water in the beakers cools back to the original temperature, record the gill beats with every 1°F. decrease in temperature. By adding ice to the water, you can also lower the temperature 5°F., recording the number of gill beats at each 1°F. decrease in temperature.

Activity 4
Effect of Temperature on Growth of Bacteria

Materials: nutrient agar slants, cultures of Serratia marcescens, inoculating loops, alcohol lamps or other heat source for sterilizing loops, incubator set at 37°C.

Procedure: Inoculate slants and incubate some at room temperature and some in the incubator. After 48 hours, examine the colonies and compare the colors.

An Example from Nature of the Effects of Temperature on Organisms*

During the past decade, marine biologists have observed a peculiar phenomenon in coral reefs at various locations around the globe referred to as coral "bleaching." The millions of individuals making up the coral reefs had died, leaving bare the carbonate skeletons of the reef organisms. Instead of the usual greens, browns and yellows, the reefs were pure white.

Although such incidents are not unheard of for small areas of reef that have been subjected to an environmental shock, such extensive and widespread incidents are new. After considerable research, scientists have hypothesized that high water temperatures may be the cause of the bleaching epidemics. Coral reefs are adapted to live within the very narrow temperature range found in tropical seas, only a few degrees of variation throughout the year. Warmer than usual temperatures in the 1980s may well have caused the severe and widespread bleaching and may indicate what the future holds for coral reefs if global warming does occur.

Coral reefs play a major role in the ecology of the oceans, providing food and shelter for many species of marine organisms, which, in turn, feed many more non-reef dwellers. Coral reefs also provide fringing reefs that protect land masses, such as Australia, from the violent actions of the open seas and coral reefs form many of the tropical islands and atolls of the world.

In addition, coral reefs play a major role in the greenhouse effect: as they extract calcium carbonate from sea water to form their skeletons, they remove a large amount of CO_2 from the water and, hence from the atmosphere. The ironic fact is that the very phenomenon causing the bleaching could injure one of the keys to reducing the greenhouse effect.

The exact mechanism by which warmer temperatures harm the coral reefs is believed to be the effect of heat on the microscopic algae that live in the cells of the corals' digestive track. Photosynthesis of these green algae provide the coral with oxygen needed for respiration; carbon dioxide produced by the coral cells enables the algae to carry on photosynthesis. Corals without the algae are unable to build reefs. Although animals, such as coral, need oxygen, too much oxygen can be toxic. In warmer waters, the algae may produce more oxygen than the cells of the coral can tolerate, causing death of the coral and subsequent bleaching.

**Bunkley-Williams, L., Williams E.H. Global assault on coral reefs. Natural History, April, 1990.*

Kirtland's Warbler - a casualty of the greenhouse effect?

Student worksheet

Connections

- Migration
- Animal territoriality
- Temperature dependent range
- Interdependence
- Rate of adaptation
- Biodiversity

Activity

Read the case study below and then answer the questions on the next page.

The case of Kirkland's Warbler

This small bird winters in the Bahama Islands and migrates north to central Michigan each spring. There, males establish territories several acres in area. Their songs serve to defend their territories from other males and to attract mates.

The pairs build nests in stands of young jack pines, which grow on the unusual coarse sandy soil found in parts of Michigan. Kirtland's warbler is extremely particular about where it lives. Its entire life cycle is dependent upon the presence of 5-6 year old jack pines and the coarse sandy soil.

Information

Kirtland's warbler is named for the Michigan farmer who first discovered it in 1851.

Like all warblers it is a tiny bird, an adult male weighs less that half an ounce.

It is rare and has beautiful gray-blue and pale lemon plumage.

The warbler's short melodic song can be interpretated as "Please, let me be-- let me be, will you please."

It has become the "pet" bird of Michigan.

These conditions are found in only a small area in Michigan, now about 1/2 million acres. Anything that reduces the number of young jack pines is bound to have an effect on the warbler.

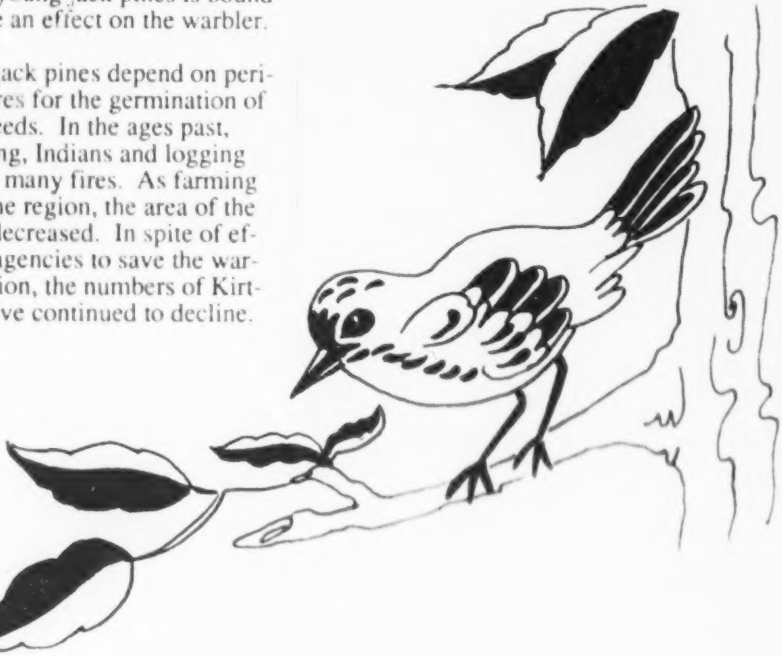
The jack pines depend on periodic fires for the germination of their seeds. In the ages past, lightning, Indians and logging caused many fires. As farming spread through the region, the area of the jack pine forest decreased. In spite of efforts of wildlife agencies to save the warbler from extinction, the numbers of Kirtland's warbles have continued to decline.

The greenhouse connection

Jack pines are extremely sensitive to temperature. Those in the area where the Kirtland's warbler lives are at the southern edge of their range. Most of the jack pines are found in the cooler climates to the north where soil conditions are unsuitable for the warblers. Any increase in temperature, as from an increased greenhouse effect, would push the range of jack pines northward. This would further reduce the habitat of the warbler.

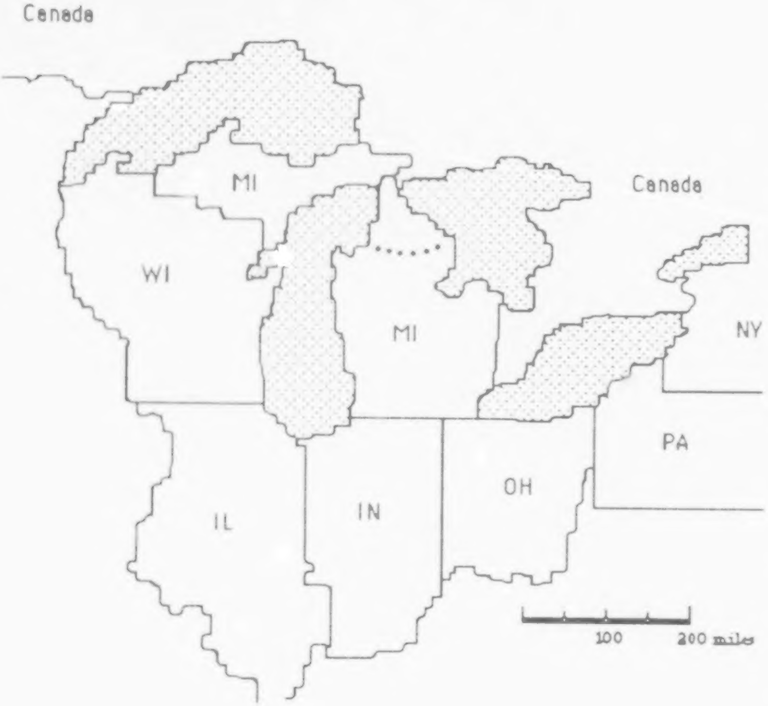
Researchers at the University of California in Santa Barbara* have suggested that decline in the numbers of Kirtland's warblers may be used as a sensitive warning of climate change in the same way that canaries, carried underground by miners, used to warn them of "bad air" by their death

* Botkin, D. B., Woodby, D., Nisbet, R. A., 1989 Kirtland's Warbler Habitats: A possible early indicator of climate warming. Unpublished manuscript



Kirtland's Warbler (Cont'd)

Student worksheet



Questions

1. A 1° C change in the annual average temperature will cause growing regions of plants to migrate 100 to 150 kilometers to the north. Climate scientists expect that at the rate we are going the increased greenhouse effect will increase the global temperature approximately 4° C by the year 2030.

How many kilometers north will the jack pine forest have moved? How many miles is that?

2. The outline map shows the present southern boundary of the jack pines. Show where the southern boundary would be in 2030, given a 4° C increase in global average temperature.

3. The area inhabited by Kirtland's warbler has a radius of about 100 kilometers. Would the amount of movement of the jack pine forest that you calculated in #2 affect the Kirtland's warbler?

4. Forests are known to have adapted to temperature changes of 1° C over 1000 years. How do you think the predicted change of global average temperature from 1.5 to 4.5° C in less than 100 years will affect the jack pines?

5. If the warmer climate causes more frequent forest fires, how might that affect your answer to #4?

6. A forest, such as the jack pines, is not just a home for one type of bird. Many types of organisms, plants and animals, live there. Over many millions of years they have grown adapted to the climate and to each other. They form a closely-knit community of organisms that depend on each other. Even if the jack pines are able to migrate northward, other members of the forest community may not be. The result would be the extinction of many organisms. Organisms that are already endangered, such as Kirtland's warbler, would be especially affected.

Do you think the preservation of a large number of species is important for humans? Why, or why not?

Extension

Although many species of plants and animals might be endangered by global warming, those already endangered now would probably be affected first.

Select a plant or animal already endangered and research its life history. On the basis of what you find out, predict how it may be affected by global warming.

Reprinted with permission from *Earth's Mysterious Atmosphere*, 1991, pp. 35-38, the National Aeronautics and Space Administration, Washington, D.C.

☛ Case No. 3 Why are scientists concerned about thinning of the ozone layer?

CLUES:

Ozone protects plant and animal life by absorbing much of the Sun's UV radiation. Scientists are not quite sure what will happen if the ozone layer becomes thin all over the planet, but because they know the harmful effects of short-wavelength UV radiation on living things, they are concerned. Even a hole over the Antarctic could have serious results. The cold oceans of the Antarctic are filled with one-celled algae called **phytoplankton**, a name that means "drifting plant." Surprisingly enough, all life in the world's oceans depends on these tiny plants. Through the process of photosynthesis, phytoplankton convert carbon dioxide and water into carbohydrates, fats, and proteins. If they are destroyed by UV radiation, the entire ocean **food web**, a whole system of **food chains**, would be upset. Also, scientists believe that these tiny plants remove about half the carbon dioxide entering the atmosphere. More carbon dioxide in the atmosphere could raise the temperature in Earth's greenhouse. This would affect all life on Earth, too.

Investigation A: Itty Bitty Swimming Things

Phytoplankton are at the bottom, or beginning, of a food chain. They are **producers**, creating their own food using the Sun's energy and nutrients in the water. They are eaten by small animals, which are in turn eaten by larger and larger animals. Eventually, the largest animals die and are broken down into nutrients by **decomposers**. The producers then use these same nutrients to create food, and the whole process continues. Scientists can guess what will happen if phytoplankton are exposed to too much UV radiation. No conclusive research has yet been done on the effect of UV radiation on decomposers. In this investigation, you will be able to look at some common decomposers.

Materials Needed

- ✓ **1 ℓ of tap water, or pond water if available**
- ✓ **dried grass or hay**
- ✓ **medicine dropper**
- ✓ **glass slides**
- ✓ **1-ℓ glass jar**
- ✓ **microscope**

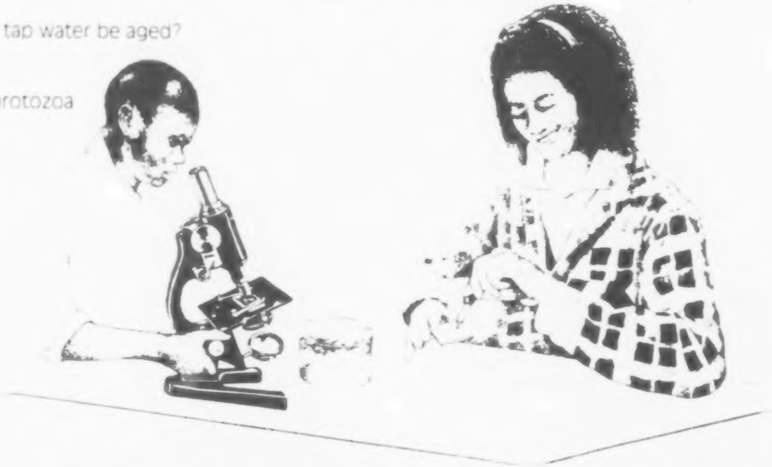
Procedure

(If using tap water, allow it to age in an open container for several days.) Pour the water into the small jar to within about 2.5 cm of the top. Add a small handful of grass or hay to the water and cover the jar loosely. Allow it to sit for about 1 week out of direct sunlight. Using the medicine dropper, take a few drops from near the top of the water's surface. Place the drops on the slide and examine them under the microscope. Sketch what you see. These are **protozoa**, single-celled creatures that have both plant and animal characteristics. These protozoa are decomposers.

Questions

❶ Why should the tap water be aged?

❷ Where did the protozoa come from?



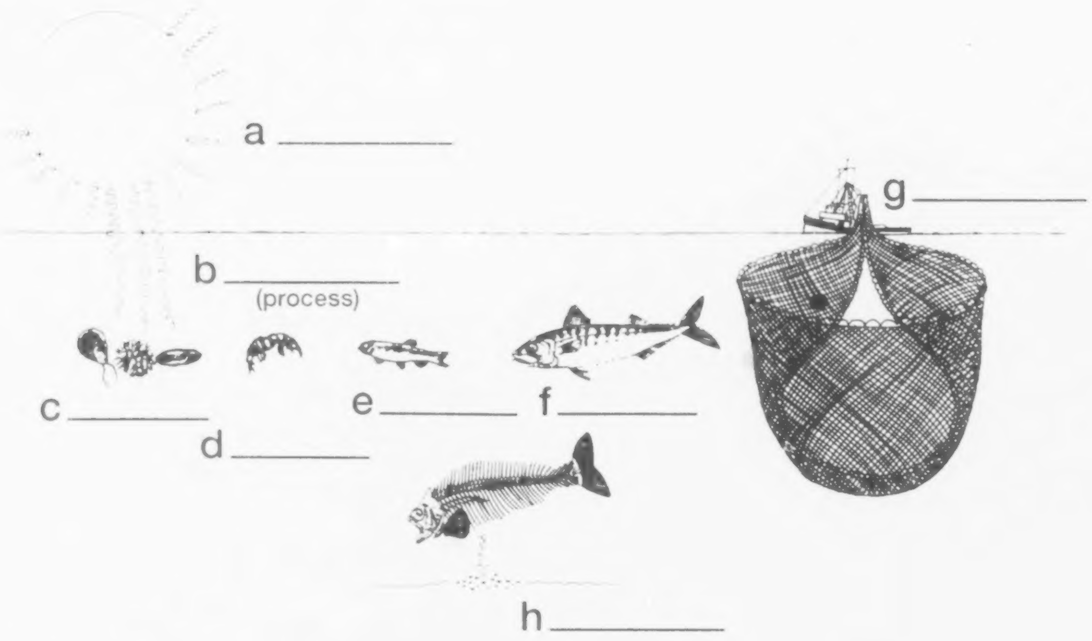
Investigation B: Food — Beginnings and Endings

Below is a word bank listing some of the elements and events in an ocean food chain

Sun
sardines
people
tuna
zooplankton
decomposers
phytoplankton
photosynthesis

Procedure

Using the terms in the word bank, correctly identify each element in the illustrated food chain



Questions

❶ Briefly describe the process of photosynthesis

❷ What are the producers in this food chain?

❸ What organism is at the top of this food chain?

❹ When fish or plankton die and sink to the bottom, what organisms break down their bodies?

Investigator's Notebook: Kilogram for Kilogram

How much do you weigh? Because humans are consumers in a food web, every kilogram of our bodies was built out of nutrients from other plants and animals. Scientists estimate that the **ratio** is about 1 to 10 (1:10). This means that to make 1 kg of your weight, your body required about 10 kg of nutrients. Those 10 kg were made from 10 times that amount of the next item in the food chain.

If you had been raised on a diet of seafood, this is the number of kilograms it might have taken to reach your present weight.

______ kg your weight $\xrightarrow{\times 10}$ ______ kg shrimp $\xrightarrow{\times 10}$ ______ kg larvae $\xrightarrow{\times 10}$ ______ kg phytoplankton

Try the same exercise with a beef diet.

______ kg your weight $\xrightarrow{\times 10}$ ______ kg beef $\xrightarrow{\times 10}$ ______ kg grain

And with a vegetarian diet.

______ kg your weight $\xrightarrow{\times 10}$ ______ kg corn or rice

Questions

❶ Can you calculate how much plankton a 130-metric-ton whale had to eat to reach its weight? (They are next to each other on the food chain.)

❷ What does this tell you about the importance of the tiny plankton?

❸ Why would it be a serious problem if too much UV light damaged the plankton?

Relating Science to . . .

Creative Writing: Every living creature has a vital function in nature's plan. Decomposers, like the ones investigated above, break down dead matter. What do you think would happen if decomposers like these were killed off or damaged by UV radiation? Write a story about a small pond, filled with turtles, fish, and plants, that suddenly loses its decomposers.

Helping Mother Earth

Take a class poll. How many students in your class drink at least one aluminum can of soda or juice every day? Did you know that if only 0.1 percent of the people in the U.S. recycled just one can a day, we could save the energy equivalent of over 13 million liters of gas per day? Extend the poll to the rest of your school.

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Answers: The Crime

CASE #1 ANSWERS

Investigation A

❶ Yes, there is a temperature difference. ❷ Plastic wrap allows warming rays through and traps heat. ❸ Individual answers: both glass and atmosphere allow light through (you can see through them); both trap heat; other answers. ❹ Individual answers: glass is dense; atmosphere is not. **Note to Teacher:** Students may say glass is solid; use this to lead to discussion of density. Encourage discussion of the fact that both are made of molecules, but molecules of glass are much more dense. ❺ Closed, parked cars will be very hot. ❻ No.

Investigation B

❶ It absorbs heat. ❷ Individual answers: they wilt, collapse, die, dry out, "cook." ❸ Too much heat was absorbed.
❹ Animals could not withstand intense heat. **Note to Teacher:** Lead to discussion of balance or equilibrium. Plants and animals need just the right amount of heat: not too much, not too little. If nature or humans disturb the equilibrium, living creatures are harmed.

Investigator's Notebook

❶ Answers will depend on the region of the U.S. in which students are living. ❷ Answers should be 2 to 9 °C higher than current temperatures.

Relating Science to . . .

Creative Writing: Encourage students to spend some time imagining before they write.

Social Studies: Student research.

History: The Industrial Revolution began in the late 1700s; most historians set the dates as 1790 to 1850. Manufacturing of items such as clothing and shoes, which had once been done in homes, was now done in factories. Machines began to be used for farming, and factories now built those machines. The major source of power was coal. Some water power was used. **Note to Teacher:** Students should be helped to see the link between the use of fossil fuels for power and the increase of carbon dioxide.

CASE #2 ANSWERS

Investigation A

❶ Moisture collects at the top of the greenhouse. ❷ Because the heat rises and the water vapor is carried to the top. There it condenses against the plastic, which is cooled by outside air. ❸ The seedling could wilt and die. ❹ Earth's plants and animals would not do well in a too-warm environment.

Investigation B

No. If students do not reach a negative conclusion here, point out the number of particles contained in the rest of the atmosphere.

Investigator's Notebook

❶ The size of the areas rich in ozone appears to be decreasing. ❷ From space, scientists can measure the atmosphere in a number of places; they can also take measurements high above Earth. If measurements are performed over a long period of time, comparisons can be made, and potential problems and changes can be identified.

CASE #3 ANSWERS

Investigation A

❶ **Note to Teacher:** Give students time to think about this. Ask: Was there something in the water that would inhibit growth of protozoa? What do we put in our drinking water to kill bacteria? **Answer:** Chlorine. Chlorine would inhibit growth of protozoa. Aging allows chlorine to dissipate.

❷ Protozoa were on the grass or hay.

Investigation B

Procedure

(a) Sun **(b)** photosynthesis **(c)** phytoplankton **(d)** zooplankton **(e)** sardines **(f)** tuna **(g)** people **(h)** decomposers

Questions

❶ In photosynthesis, green plants use chlorophyll and light to transform water and carbon dioxide into food in the form of glucose (sugar). Oxygen and more water are also produced. ❷ Phytoplankton ❸ People ❹ Decomposers

Investigator's Notebook

Answers will depend on students' weights. **Note to Teacher:** Students probably know their weights in pounds. Have them convert to kilograms first. **(1)** A 130-metric-ton whale would have to have eaten 1,300 metric tons of plankton to reach its weight. **(2)** Individual answers. Encourage students to see the importance of plankton. **(3)** Entire food webs would be affected.

Relating Science to . . .

Note to Teacher: Be sure to have students formulate hypotheses before they begin. This is fairly new research. Answers are not known.

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Meadows in the Sea

Whale Tales

The great whales understand the importance of plankton to their own survival. If we could hitch a ride with a whale and ask it to tell us about the plankton, it might say something like this:

"The plankton are small, very small, and they are not good swimmers. There are many different types, including both animal plankton (*zooplankton*) and plant plankton (*phytoplankton*). We call the phytoplankton "meadows in the sea." All animals in the ocean, large and small, depend in some way upon the plankton for survival. There are those of us who eat the plankton and there are those who eat the plankton-eaters. The phytoplankton are so small I can't see individuals with my eyes. In the summer, the phytoplankton bloom and can be so numerous (7 billion/square meter) that it is like swimming in a thick brown soup. The zooplankton are larger, up to 2 inches in size. The zooplankton are especially important to whales, since they are our main source of food. During the summer, I have swum in waters that had miles and miles of zooplankton. During the day I find them in deep water (600+ feet). But at night, they move up to the surface and feed on the phytoplankton."

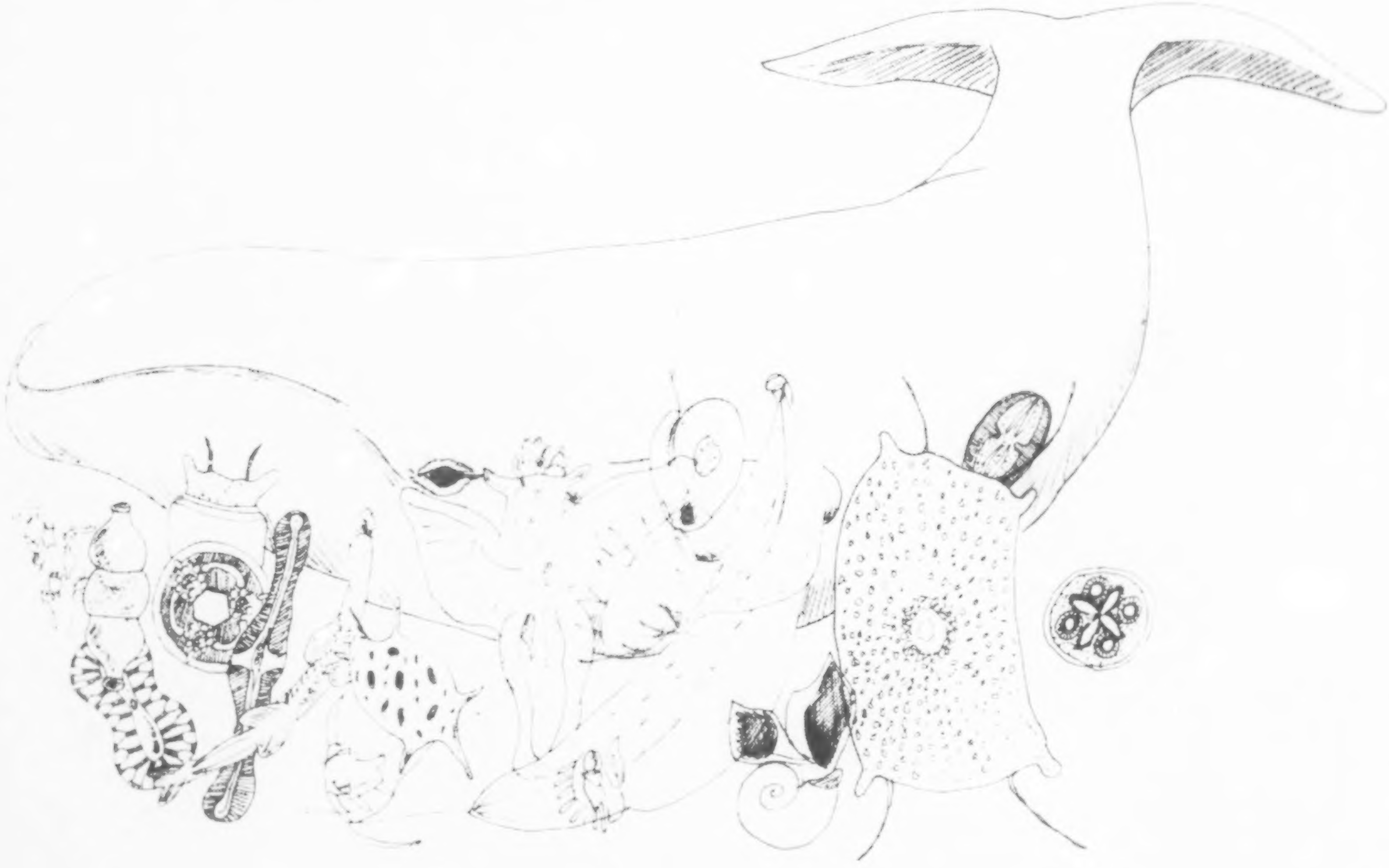
What We Will Discover

In this section we will discover the fascinating world of plankton. We will discover the unique types of plankton and learn about their importance to our oceans.

How We Will Do This

We will read about plankton and work on activities that add to our understanding of plankton.

Reprinted with permission from *Whales in the Classroom, Volume I: Oceanography*, Larry Wade, 1992, pp. 62-75, Singing Rock Press, Brooklyn Park, MN.



Terms for the Oceanographer

Baleen – *Baleen* are the thin plates that hang from the upper ridge of the mouth of the whale. The baleen plates are used for straining water and capturing prey while the whale feeds on plankton or fish.

Behavior – The *behavior* of an animal relates to how an animal is acting or what it is doing.

Bloom – A *bloom* is a sudden increase in a population of animal or plant plankton.

Chlorophyll (klor´-o-fil) – *Chlorophyll* is the green substance in plants that does an important manufacturing job. With chlorophyll, the plant is able to use the energy of the sun to manufacture carbohydrates (starches) and sugar in the process known as *photosynthesis.*

Chloroplast (klor´-o-plast) – *Chloroplasts* are the cells within plants that contain *chlorophyll.*

CO_2 – The chemical symbol of *carbon dioxide.* Carbon dioxide is breathed out by animals and utilized by plants in *photosynthesis.*

Detritus (di-try´-tis) – *Detritus* is decayed animals and plants. The *detritus* provides the nutrients that are essential to *phytoplankton* growth.

Larva – A *larva* is an animal in the first stage of life after the egg has hatched. Animal groups that have a larval stage include insects, crustaceans (crabs), molluscs (snails), worms, and fish.

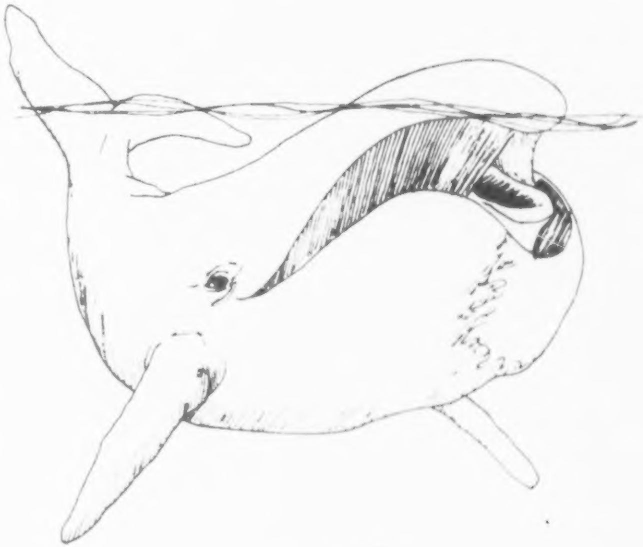
Photic zone (fo´-tic zone) – The *photic zone* of the ocean is the depth to which light will penetrate (100 feet in murky inshore water).

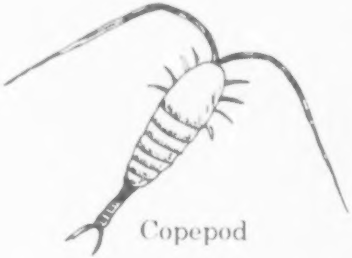
Photosynthesis – The process in which plants convert CO_2 and water into carbohydrates (starches) and sugar by using sunlight and the plant's *chlorophyll.*

Phytoplankton (fy´-to-plankton) – *Phytoplankton* are plant plankton. They are microscopic in size.

Zooplankton (zo´-plankton) – *Zooplankton* are animal plankton. They are visible without microscopes and grow up to 2 inches in size.

Go for it!





Copepod

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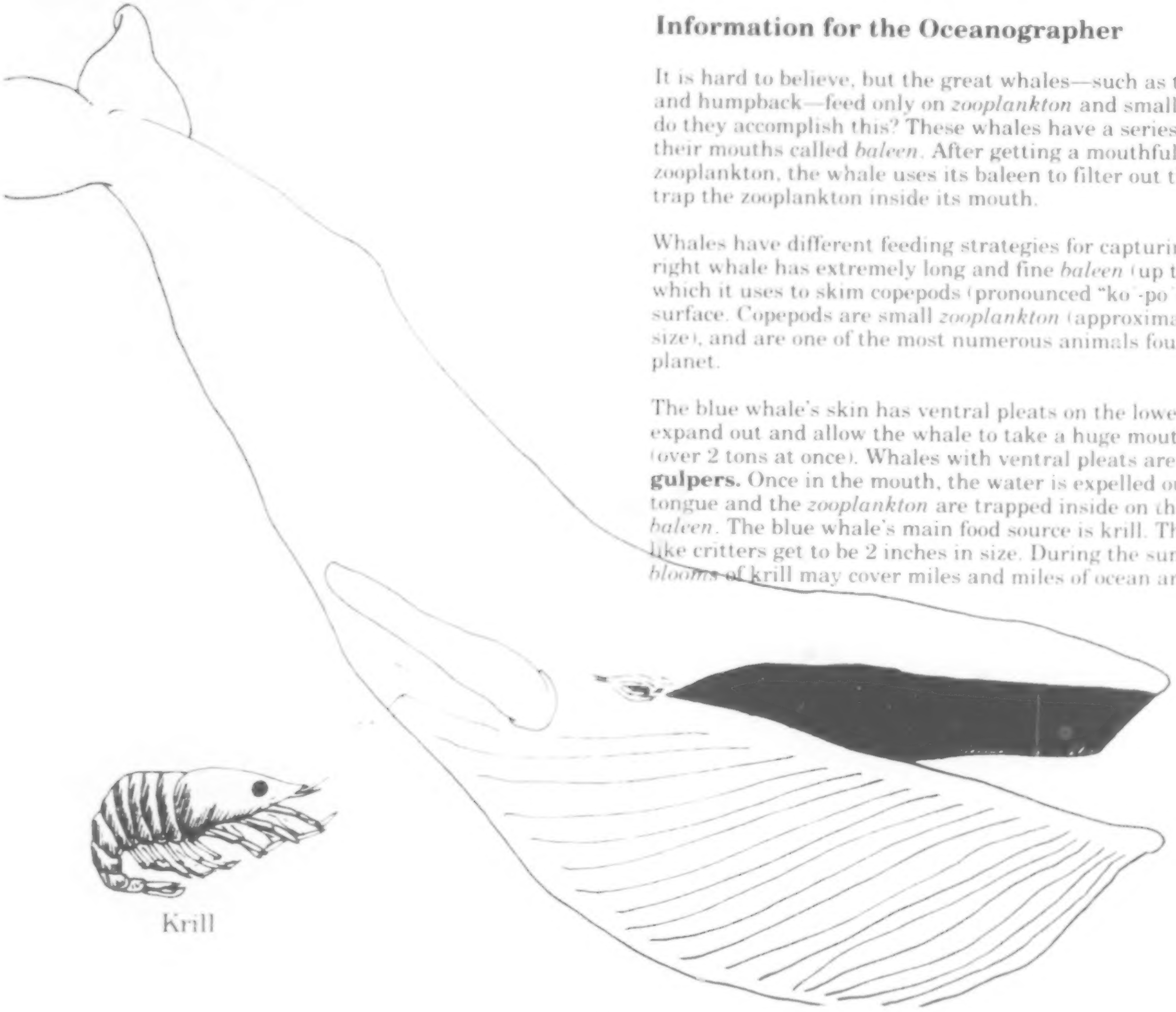
Information for the Oceanographer

It is hard to believe, but the great whales—such as the blue, fin, and humpback—feed only on *zooplankton* and small baitfish. How do they accomplish this? These whales have a series of strainers in their mouths called *baleen*. After getting a mouthful of water and zooplankton, the whale uses its baleen to filter out the water and trap the zooplankton inside its mouth.

Whales have different feeding strategies for capturing prey. The right whale has extremely long and fine *baleen* (up to 11 feet) which it uses to skim copepods (pronounced “ko´-po´-pod”) at the surface. Copepods are small *zooplankton* (approximately 1/4 inch in size), and are one of the most numerous animals found on this planet.

The blue whale's skin has ventral pleats on the lower jaw that expand out and allow the whale to take a huge mouthful of water (over 2 tons at once). Whales with ventral pleats are called **gulpers.** Once in the mouth, the water is expelled out by the tongue and the *zooplankton* are trapped inside on the whale's *baleen*. The blue whale's main food source is krill. These shrimp-like critters get to be 2 inches in size. During the summer huge *blooms* of krill may cover miles and miles of ocean area.

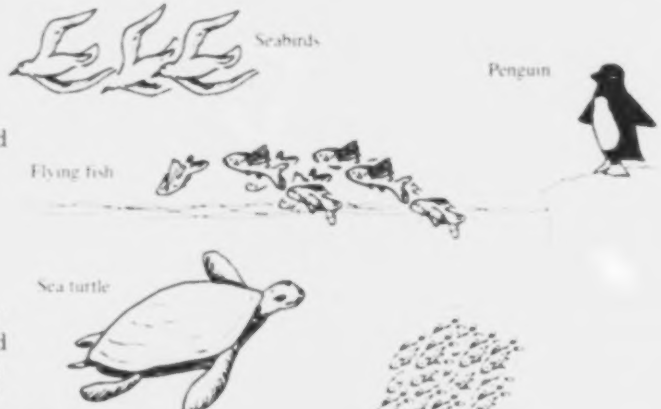


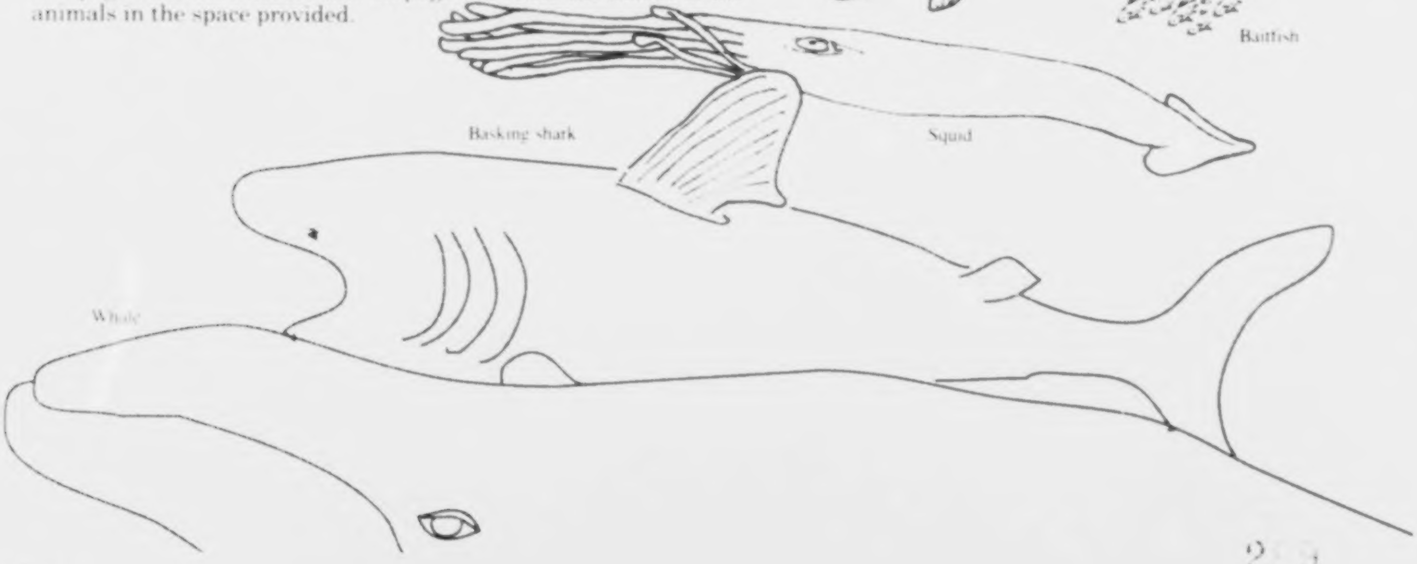
What Are Zooplankton?

Zooplankton is a general term for many types of animals that swim poorly. They range in size from microscopic to 2 inches. Some animals spend only the *larval* stage of their lives as plankton, while others live their entire lives as plankton. The most common zooplankton are copepods (pronounced "ko´-po´-pods") and krill. In a given sample of zooplankton, 50–75% of the sample may be copepods and krill. These small creatures (3/8 to 2 inches in size) are considered to be the most important animals found in our world today. They are a primary source of food for a number of different species of animals, including seabirds, herring, whales, and squid.

So You Want to Be an Oceanographer

The uncompleted diagram on page 67 illustrates the importance of *zooplankton* to our marine environment. All of the animals pictured on this page depend on zooplankton for food. Match the animals on this page with the correct hints on page 67. Write the names of the animals in the space provided.





One of the few reptiles that live in the oceans

A schooling fish

Can glide above water to escape enemies

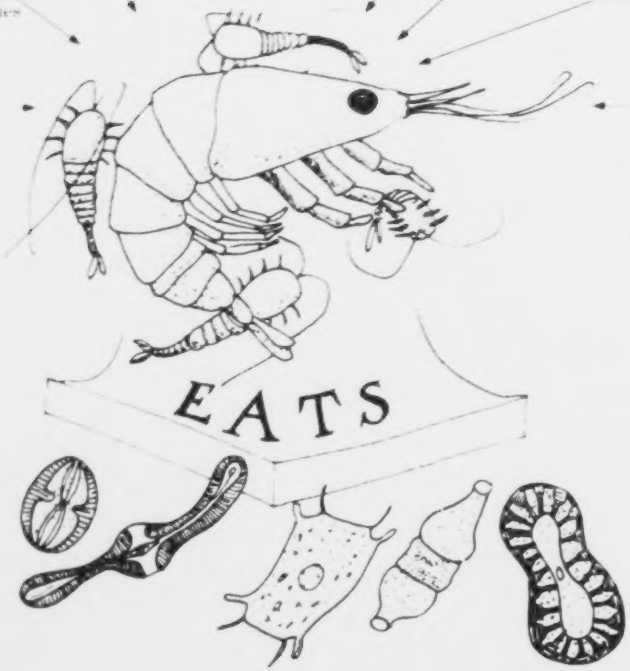
Lives on ice floes

Its cousins have extremely sharp teeth

Glides and flies in the air, looking for food

Uses tentacles to catch its prey

Largest animal on the earth



Whales and Plankton

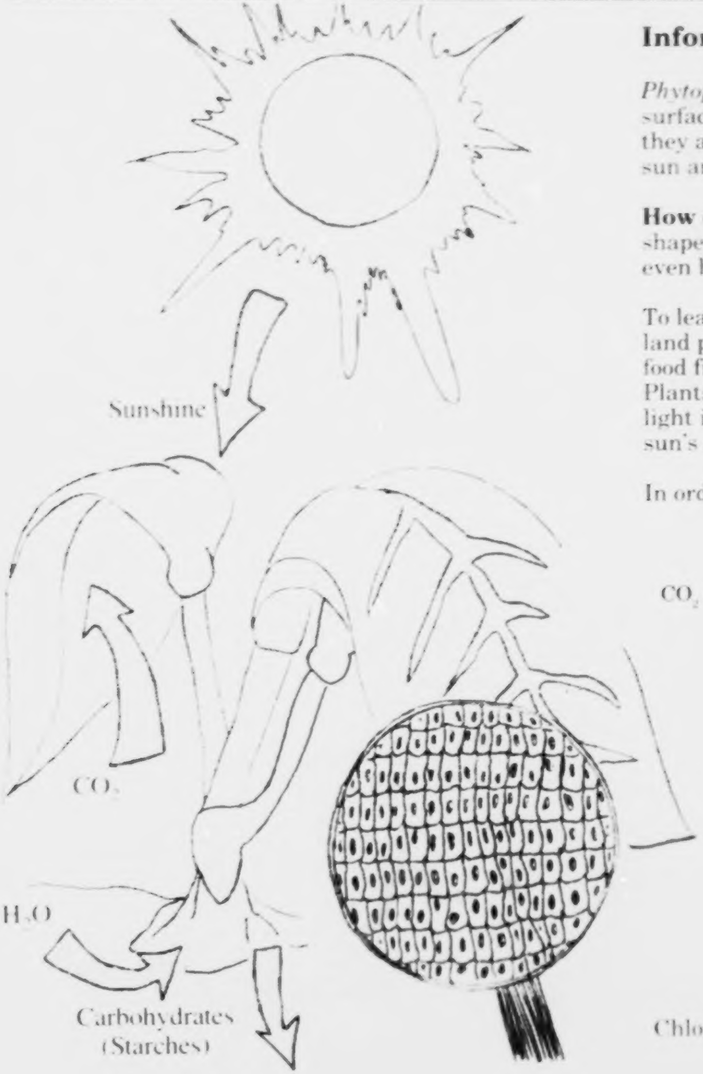
How could a huge whale possibly survive on such small creatures as copepods and krill? During the summer months, the *zooplankton* become so numerous that there may be miles and miles of zooplankton in the feeding grounds of the whales.

So You Want to Be an Oceanographer

To get some idea of how abundant krill are during a summer plankton *bloom*, we will make some mathematical estimates of the number of krill eaten by blue whales. In the Gulf of St. Lawrence Estuary, Quebec, Canada, over 200 blue whales have been identified by researchers. In this activity, assume that only 50 blue whales spend the entire summer in the Gulf. Also assume that a single blue whale will eat up to four tons of krill in a day.

rovince of
Quebec
Newfoundland
Gulf of
St. Lawrence
Nova Scotia
Atlantic Ocean
Montreal
Maine

1. How many tons of krill are eaten in a day by all of the blue whales?
2. How many pounds of krill are eaten in a day (2,000 pounds = 1 ton)?
3. Blue whales remain in the Gulf of St. Lawrence from approximately July 1 to October 15. How many tons of krill are eaten in a season by all of the whales?
4. How many pounds of krill are eaten in a season by all of the whales?
5. There are roughly 100 krill/pound. How many actual krill are eaten by blue whales in the Gulf of St. Lawrence in one summer?



Information for the Oceanographer

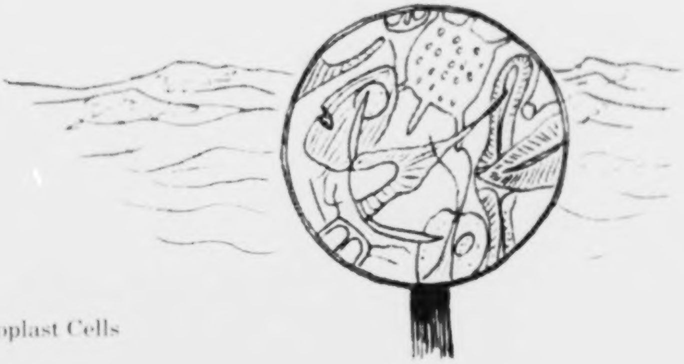
Phytoplankton are microscopic plants that float near the ocean's surface. Phytoplankton are the basis for all food in the oceans, since they are able to produce food (carbohydrates and sugar) from the sun and other natural elements (water and carbon dioxide).

How could *phytoplankton* possibly be plants? They are odd-shaped microscopic objects that float around in the ocean and don't even have any roots or leaves.

To learn more about how plants work let's look more carefully at land plants. Plants are the only living things that can manufacture food from natural elements. This process is called *photosynthesis*. Plants have special cells called *chloroplasts* that help convert sunlight into food. These cells contain *chlorophyll* which "captures" the sun's energy.

In order to *photosynthesize*:

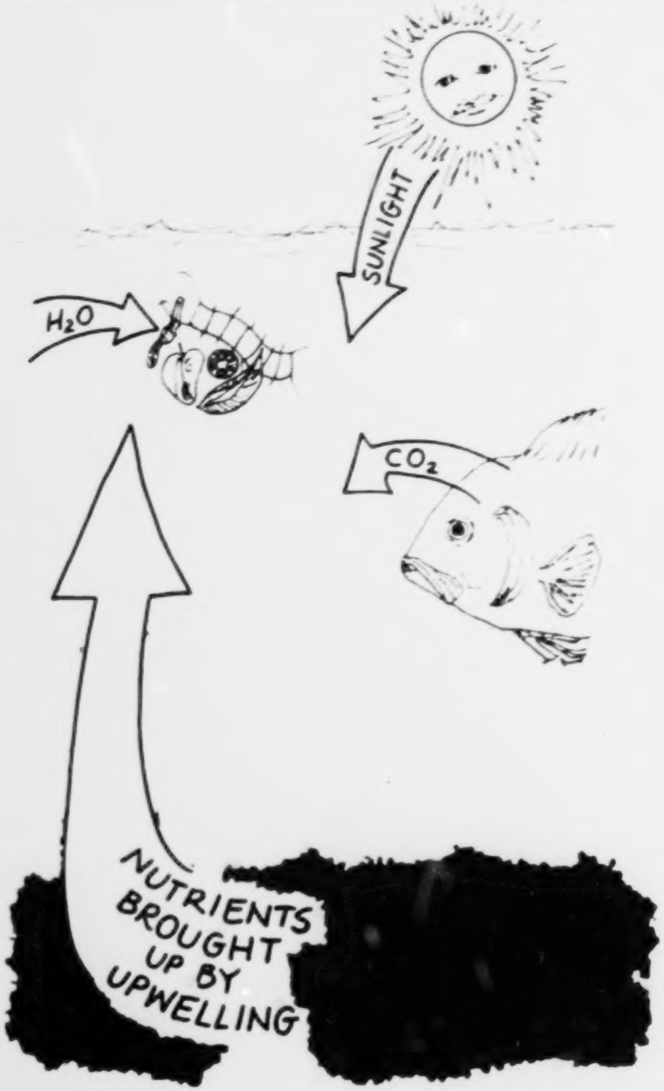
Plants use:	**Plants make:**
CO_2 (*carbon dioxide*) + H_2O (water) + sunlight	= carbohydrates and sugars



Chloroplast Cells

Are Phytoplankton Really Plants?

Phyto Phacts



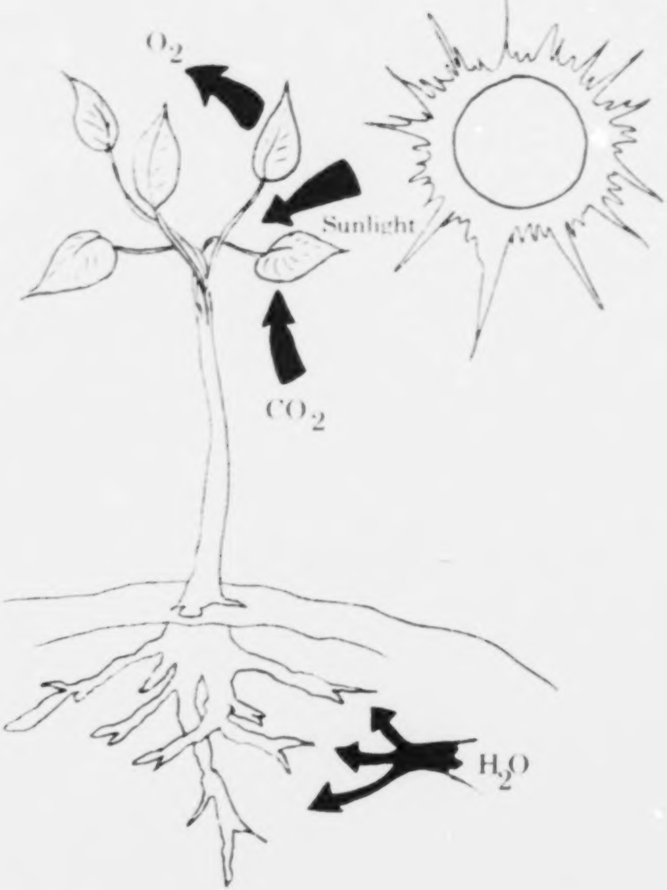
1. In order to photosynthesize, *phytoplankton* need *CO_2*, water, and sunlight. Oxygen is given off during *photosynthesis* by the plankton and is used by fish and other animals for breathing. The nutrients provided by the *detritus* on the ocean floor increase the rate of phytoplankton growth.

2. *Phytoplankton* need the sun to *photosynthesize*. As a result, most phytoplankton are found within 100 feet of the ocean surface in the *photic zone*. Beyond that depth the phytoplankton cannot effectively utilize the sun's energy.

3. Most types of *phytoplankton* are **flattened,** which helps them to float and to gather more sunlight. Phytoplankton also have special cells called *chloroplasts*, which contain *chlorophyll*. With chloroplasts, they are able to capture the energy from the sun and convert it into food.

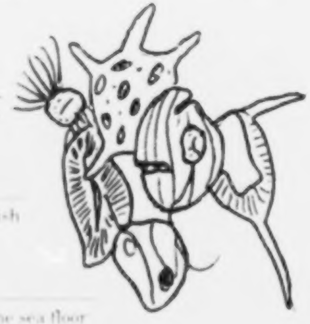
So You Want to Be an Oceanographer

The diagram on the left shows a land plant with all the parts and elements necessary for its survival. Below is a diagram of *phytoplankton* with a number of clues. Using the information on the left and the information given in "**Phyto Phacts**" (page 70), write in the correct response for each clue.



1 ______________________
What shape helps gather more solar energy?

2 ______________________
Energy used for photosynthesis



3 ______________________
Given off by plants and used by fish

4 ______________________
Comes from detritis on the sea floor

5 ______________________
Special cells used for photosynthesis

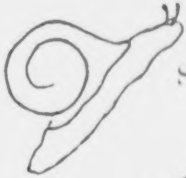
6 ______________________
2 chemical substances needed for photosynthesis

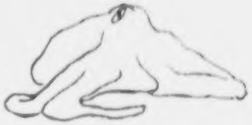
The Zooplankton Nursery

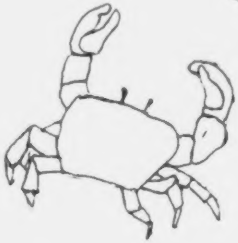
The *zooplankton* serve as a "nursery" for many *larval* animals. The animals hatch from eggs, and the larvae live as zooplankton. Some will remain as plankton for years, others for only weeks.

So You Want to Be an Oceanographer

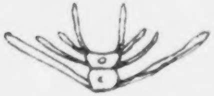
Pictured on this page are several types of adult animals that live part of their lives as plankton. The adults are pictured on the right and the *larvae* are pictured on the left. Match each adult with its larva, by placing the correct letter of the larva on the line beside the adult.

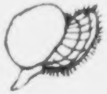

Snail _____

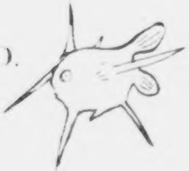
Octopus _____


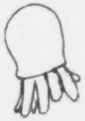

Crab _____

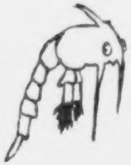
A.

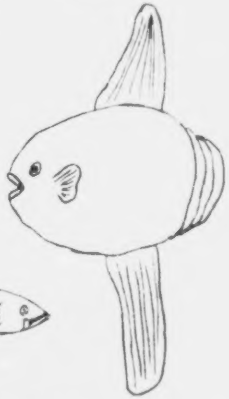
B.


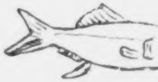
C.


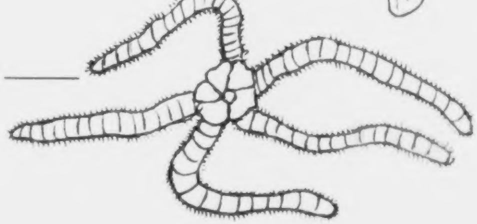
D.


E.


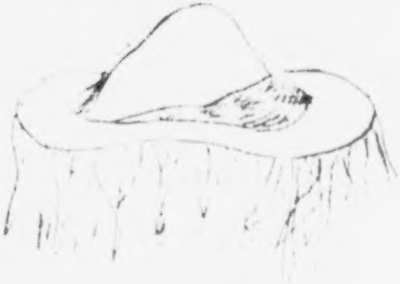
F.


Mola-Mola _____


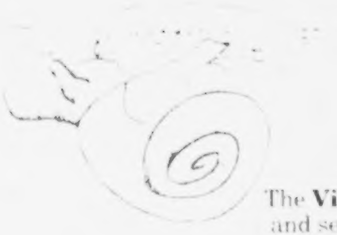
Herring _____


Brittle Star _____


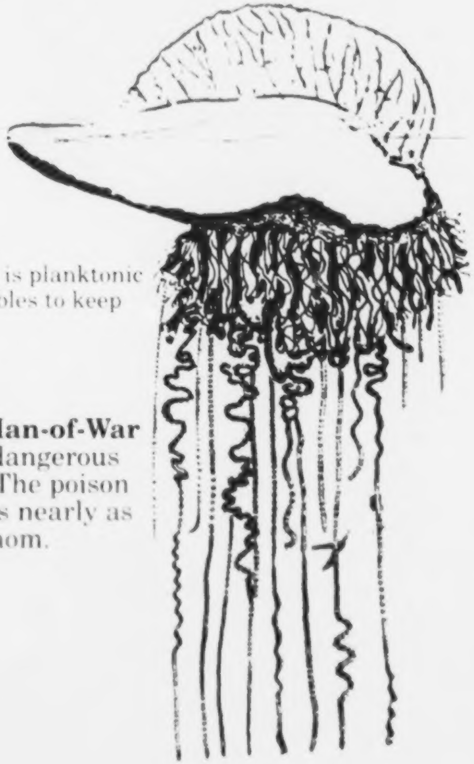
Weird Plankton



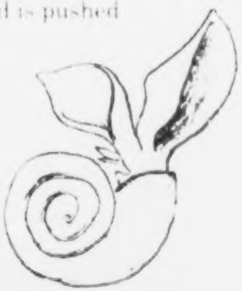
The **By-the-Wind Sailor** is a type of jellyfish that floats at the surface and is pushed by the wind.



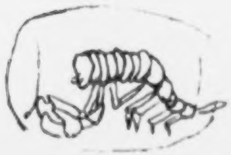
The **Violet Snail** is planktonic and secretes bubbles to keep it afloat.



The **Portuguese Man-of-War** is one of the most dangerous marine creatures. The poison from its tentacles is nearly as strong as cobra venom.



The **Sea Butterfly** is a snail whose wing-like foot helps it to "fly" through the water.



The **Phronima** is an odd crustacean that eats a jellyfish or tunicate (a jellyfish-like animal) and then uses the floating portion of the animal to make its home.

Up Close and Personal with a Famous Oceanographer

Dr. Stormy Mayo
Marine Biologist

Dr. Mayo is the director of the Center of Coastal Studies in Provincetown, Massachusetts. The research at CCS focuses around humpback, fin and right whales. In 1991, Stormy initiated a study on plankton to try to learn more about the endangered right whale's main food source. Dr. Mayo has a varied background in marine biology. He has studied plankton, fish, whales, and the effects of pollution on the marine environment. Stormy's excitement and dedication to learning about the oceans is an inspiration for all.

How did you first get interested in the oceans?
My father spent his whole life on the sea. He was a fisherman, so I went out on boats with him a lot. My father had a real interest in the way the ocean worked. He turned me on to looking at the ocean closely.

What has kept you going throughout your career?
My only reason for doing any of this stuff is because it is exciting. I think it is "neat." I don't think there is a better reason for doing anything. I am not really excited about making money.

The work that I do with whales, or even more so with plankton, is absolutely the most intriguing fantasy. I use the word fantasy in all the different contexts. I think the best part of science is fantasy and imagination. Scientists don't like to call it that because it is not "cool," so they call it a hypothesis. But fantasy and imagination are the best parts of science and the things that make science vital. If science becomes reduced to not dreaming dreams that are excessive and absurd, then science never advances. It becomes technology and not science. Imagination is the leading edge of science. The next level, since we call ourselves scientists, is to sit down and really prove or disprove the visions that we have had.

If you were to give a young biologist one piece of advice, what would you tell him or her?
Certainly to do your work well, but yield always to the passion that you feel about the Earth and the animals. Don't believe that being a scientist means you are passionless. If there is anything we need in biology and the ecological sciences, it is a devotion to one's enjoyment of the work and one's passion for it. Give me someone who cares a great deal, who is rather well structured, and you've got someone who can make it in marine sciences.

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What do you find so interesting about plankton?
I work on whales now, and they are extraordinary creatures; but the little, tiny animals of the oceanic systems are at least as interesting. I think the reason is that plankton are the "beating heart" of the Earth. The phytoplankton and zooplankton may even dwarf the great rain forest, the temperate forests…all the forests together in terms of productivity. Whales are neat, but dealing with the absolute basis of life on Earth is even more of a turn-on.

Tell us about the plankton study you are doing in the Gulf of Maine.
We have watched right whales come here to feed. They are now on the brink of extinction (only 200+ animals in the entire North Atlantic Ocean). This is obviously a habitat which is absolutely crucial to their future and has been for a long time. This area is one of the last stands of the animal. They are grazers, feeding on copepods at the surface. We have discovered ultra dense swarms of zooplankton whose concentrations are greater than 2 million per cubic meter. These concentrations are ten times higher than anything ever recorded in the North Atlantic. All of this stuff is flabbergasting. The concentrations are like a swirling ribbon less than 1/2 meter across and go on for up to several hundred meters. It appears that it happens along current edges (micro frontal areas). Right beside the ultra dense swarms of plankton are areas of extremely low concentration (500–1,500 animals per cubic meter).

We can study this better than anyone else, because the right whales are here. We can't find the dense concentrations unless we have right whales. Give me a right whale and it will find one of these things. Give me no right whales and I can go out with the fanciest gear and I can't find the dense patches of plankton. Isn't that neat! The whale has an extraordinary system for finding these things and we can't duplicate it. It is the dense patches of plankton that appear to support right whales. So it is really important from the point of right whales to find out what is going on here.

You have been involved in freeing humpback whales from nets. How does it feel when you have set a whale free?
Most of the whales we work with are tangled in gill nets that are anchored on the bottom. We have set free nine animals, and there have been a number of others that we may have helped. Most of the time it is an unbelievable relief, because it is very scary working over animals that are as big and powerful as they are.

Why do you do this if it is so dangerous?
I think that there is a personal obligation for anyone who deals with a large and endangered animal. Dianne Fosse is an historic example (*Gorillas in the Mist*). Let's face it. She put her life on the line trying to protect the gorillas. We have really got to recognize that saving the rain forests, oceans, and endangered species is a personal responsibility that cannot be avoided.

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Catchin' Some Rays

NAME:	Kay Baggett
SCHOOL:	Ocean Springs Junior High
SCHOOL DISTRICT:	Ocean Springs Public Schools, Ocean Springs, MS
GRADE/SUBJECT:	9th Grade Biology

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INTRODUCTION:
For the first 500 million years of Earth's history there was very little oxygen and no ozone high in the stratosphere. Life could only exist in the seas where it was shielded from the DNA-damaging effects of ultraviolet light. As cyanobacteria pumped oxygen into the atmosphere as a by-product of photosynthesis, that oxygen began to rise in the atmosphere to a point at which the ultraviolet bombardment could form ozone (0_3) as oxygen molecules (0_2) disassociated. Ozone is continuously replenished in the stratosphere and there it does all terrestrial life a service: it protects surface life from the damaging rays of UV that would otherwise make life very difficult, if not impossible, on Earth's surface. Because of this protecting blanket of stratospheric ozone, life on Earth has continued to evolved for the last 3 to 4 billion years, affected little by those high-powered UV rays. Recently, however, there have appeared areas, especially in the Antarctic, where there is a drastic thinning in this protective blanket. More and more ultraviolet rays are penetrating the stratosphere, bombarding the surface. Scientists have traced this ozone depletion primarily to CFCs and other halocarbons, man-made chemicals which are used as refrigerants, solvents, and propellants in industrial societies. No one yet knows the exact extent of the damage to anticipate from this depletion but it cannot be beneficial for the fragile DNA of our surface organisms to be exposed to this irridation. We can foresee increased cancers and extensive crop failures but what the effect will be on our "lesser" fellow travelers, no one can accurately predict.

PROBLEM: Is bacterial growth affected by different wavelengths of light?

MATERIALS: (per laboratory group): 5 petri dishes, culture medium, bacteria culture, marking pencil, infrared light source, ultraviolet light source, incandescent light source, acetate sheets, washable marker.

PRECEDURE:

1. Collect your materials and prepare your culture medium in the petri dishes.
2. On the bottom of each dish indicate your laboratory group and the light you are using with this dish.
3. Inoculate your dishes with a bacterial sample. (obtain sample from your teacher).
4. Put one inoculated petri dish in each of the following sites found at different places throughout the room: a sunny window; a drawer (dark) in a cabinet with UV light source; in a cabinet with infrared light source; and in the room with a fluorescent or incandescent light source.
5. Each day when you come into this class for the next two weeks, observe your petri dish and note your observations.
6. To measure bacterial growth place an acetate sheet over the colony appearing (or not) in each petri dish. Mark outlines of the colony on the acetate sheet and label the light

source. Place the acetate sheet over a sheet of graph paper and count the squares covered by the colonies. Record these number in your data sheet.

7. At the conclusion of your investigation, clean your equipment according to your teacher's instructions.
8. Work together to analyze your data and formulate your conclusions.

Record the number of squares covered by each colony below.

Data Sheet

day	sunlight	incandescent	UV	infrared	dark
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

Conclusions and applications:

1. Under which light source did your bacteria grow best? ____________________
   Under which light source was growth the worst? ____________________

2. Explain why bacteria did most poorly under this wavelength of light: ____________________
   ____
   ____

3. If bacteria are damaged by this wavelength of light, what are the implications for more complex organisms? ____________________
   Explain your answer: ____________________
   ____

4. There are some places where bacteria lie at the base of the food chain. If these areas are at the Earth's surface, describe what might be expected to happen to those ecosystems: ____________
   ____
   ____

5. In every ecosystem bacteria are the primary decomposers. Describe the implications of their disappearance from the ecosystem: ______________________________

____

6. Predict which might happen to pathogenic bacteria should they be exposed to these light wavelengths: ______________________________

____

Explain your predictions: ______________________________

Impact of UV on Plants

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NAME: Karen Richardson

SCHOOL: Mary G. Montgomery High School

SCHOOL DISTRICT: Mobile County Public Schools

GRADE/SUBJECT: 9th-10th grade Biology

TOPIC AND ISSUE STATEMENT: The ozone layer, our protection from harmful solar radiation, is being depleted by a group of pollutants that are clearly anthropogenic. CFC's (chlorofluorocarbons), the gases used in spray cans, air conditioners, and refrigerators, are creating a series of chemical reactions which tear apart the ozone molecule. This molecule is then no longer able to block out the ultraviolet radiation of the sun. Without this layer of protective ozone in our atmosphere, life as we know it could not exist on our planet. Increased radiation to the earth's surface is presently causing a variety of problems to life on earth. There are increasing cases of skin cancer, damage to fisheries, and damage to plant tissue.

OBJECTIVES: The student will be able to describe the effects of ultraviolet radiation on plant life. Students will be able to discuss the major causes and effects of ozone depletion.

MATERIALS: Booklet "What would it be like to live in a world where the sun was dangerous?" Hawaii Sea Grant.
Each group will need:

- 2, two liter coke bottles
- potting soil
- rye grass seeds
- 2 ultra violet lights
- Globe Book Co. Biology

REFERENCES: Articles and workshop notes on ozone depletion - Global Environmental Issues Workshop 1992

STRATEGY: In the chapter on conservation, we will talk about pollution. I plan to use this activity in that portion of our study.

ACTIVITY: After a class lecture about ozone depletion in our atmosphere (cause and effects will be discussed), students will participate in the following activity. Students will soak rye grass seeds over night. They will plant an equal number of seeds in each of two plastic drink bottles. One will be put under an ultraviolet light and the other will be allowed to grow under ambient conditions in the classroom. It may be necessary to establish the length of time the light will remain on each day. For a minimum of two weeks, students can monitor the plants. They should keep data tables with the following information: each day record the number of plants that have germinated, the height of the plants in each pot, and any observable variations in color or plant conditions. At the end of the specified time period, have the class graph their results.

Each laboratory group could prepare a poster which shows their graphs and tells the causes of the increased radiation in the atmosphere. They may include pictures of aerosols, refrigerators, or airconditioners.

POSSIBLE EXTENSIONS:

a) Because pines are so sensitive to increased levels of radiation, these seedlings may be useful plants for germination purposes in this study.
b) Students may wish to research the history of ozone depletion. It is so recent that students may find it of special interest.
c) Try the activity with marine organisms such as a fouling organisms that can be grown on a microscope side in a marine aquarium.

TEACHER'S EVALUATION:

1. What is the relationship between ozone depletion and increased ultraviolet radiation?
2. Describe how plants may be affected by increased levels of ultraviolet radiation.
3. Name two factors that have contributed to the ozone depletion in our atmosphere. What compounds are involved?

***Caution should be used with ultraviolet lights. Read all safety procedures!

VI

DECISION-MAKING UNDER SCIENTIFIC UNCERTAINTY

VI. DECISION-MAKING UNDER SCIENTIFIC UNCERTAINTY

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Information Unit on Climate
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Are climate models reliable ?

▲ **Defining "success" for a climate model is surprisingly difficult.** Inevitably, models (fact sheet 14) are good at simulating some aspects of the climate system and less good at others. But since we depend on these models to predict the possible consequences of emitting greenhouse gases, we would clearly like to know how reliable they are overall.

▲ **The reliability of models can be estimated by comparing model-climates with the present climate, with reconstructions of past climates, and with each other.** Comparing models with each other may be instructive, but it cannot be an absolute guide to their accuracy since different models generally rely on similar approximations and work in similar ways. If two models give the same answer, it may be because they both contain the same errors. Consequently, short of waiting until after climate change has occurred, the best guide we have for judging model reliability is to compare model results with observations of present and past climates.

▲ **Our lack of knowledge about the real climate makes it difficult to verify models.** It is hard to say if a model has the answer right if we don't know what the right answer is. Observational data on many key climatic variables is extremely limited, particularly for sluggish components of the system such as deep ocean currents. Slow components must be observed over long periods of time before they reveal their full range of behaviour, and the systematic records that do exist are all rather recent. Even things like rain- and snowfall rates are not known precisely, particularly in unpopulated regions and the open oceans.

▲ **There is no simple universal measure of model "accuracy".** Because the climate system is much too complicated to be modelled from "first principles" alone, scientists must use observational data to develop climate models. But this means that they could always "force" a model to reproduce a particular set of observations by telling it exactly what those observations are and making it flexible enough to fit them exactly. Obviously, this is not what climate modelling is about. But it shows that defining what it is for a model to be "good" can become quite complicated. We cannot simply ask "how well does model A reproduce the present climate?"

▲ **When testing a climate model, we must ask "how much did we have to tell model A about the present climate, and how well did it reproduce the rest?"** If scientists drive a modern atmosphere model with observed sea-surface temperatures, for example, it will simulate large-scale patterns of winds, surface pressure, air-temperature and precipitation with considerable skill. Likewise, if they "blow" and "rain" observed winds and precipitation onto an ocean model, it can reproduce the major ocean currents. Clearly,

Source Houghton et al. eds., 'Climate Change The IPPC Scientific Assessment', Cambridge (1990) there is much that is correct in these models. But if an atmosphere and an ocean model are coupled together without any adjustment to make sure they "match", the coupled model tends to evolve towards a much less realistic climate. This is to be expected, and does not necessarily mean the models are all that bad, for the following reason:

▲ **Feedbacks between different climate components amplify some model errors . . .** If, for example, the model-atmosphere happens to produce winds that are slightly too weak over a particular part of the ocean, the sea-surface temperature would be affected. This in turn might, under certain circumstances, make the winds weaker still. So errors that would be almost undetectable if either the atmosphere or ocean were modelled independently can become quite serious when the two are coupled together. There are methods of overcoming such feedback loops, but they tend to involve somewhat arbitrary-looking fixes.

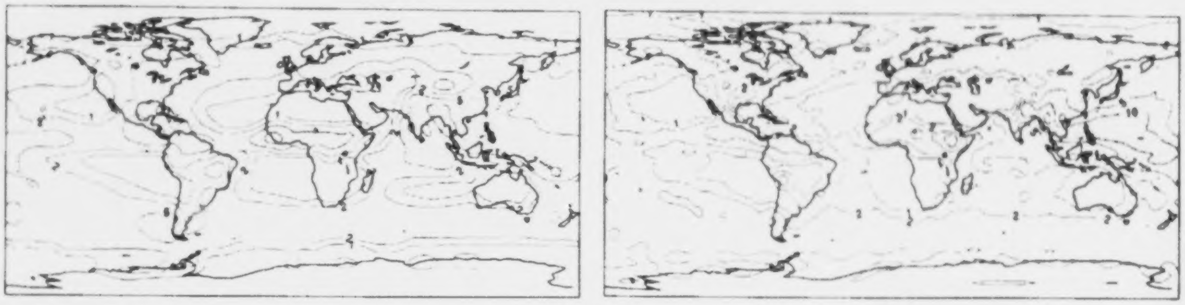
▲ **. . . but other errors are self-correcting.** Models are designed to conserve quantities such as energy and water. If it rains too much in a particular grid-box, the model will run out of water there and the rainfall will shut off. Listing all possible sources of error in a climate model would therefore not only be difficult, but might well give the misleading impression that the models are worse than they really are.

▲ **There are several ways of double-checking whether advances in modelling are really improving model reliability.** Increasing the grid-resolution of an atmosphere or ocean model, or introducing more realistic representations of particular processes, generally (but not always) makes the climate which it simulates more realistic. Moreover, changes in models often affect climate simulations in ways that are understandable in physical, real-world terms; increasing an ocean-model's resolution, for example, makes the simulated Gulf Stream stronger, and thus enhances heat transport to the North Atlantic. The fact that climate simulations improve in a reasonably consistent and comprehensible way suggests that scientists are making successively better approximations to the real climate system.

▲ **Models are becoming more reliable.** New models for simulating the present climate are also simulating year-to-year climate variations and key features of past climates with increasing realism. This is extremely encouraging, since it suggests that models are already capable of, and are becoming better at, capturing the essential features of the long time-scale variations that matter for climate change.

▲ **Climate models are scientific tools, not crystal balls.** Models don't serve up answers on a plate: the work involved in interpreting the results from a climate simulation using a large climate model is often greater than the work involved in setting up the simulation in the first place. A modern climate model is a remarkable tool, and definitely the best method scientists have for investigating climate change. But there is nothing magic to it. It remains a tool, to be interpreted carefully and responsibly.

Comparing models and observations



(a) (b)

Rainfall during the Northern Hemisphere summer (June, July and August): *(a) observed and (b) as simulated by a climate model with sea-surface temperatures prescribed from observations. This model from the Canadian Climate Centre is typical of the generation used for CO_2 doubling experiments in the late 1980s.*

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EDITORIAL

Science and Society

The ways in which science and society are governed are quite different and the difference causes friction when scientific progress is of societal concern. Science is dealing with the unexpected, the frontier, the search for a new path, not with the predictable, the established edifice, the walk down the well paved road. In the aggregate, science is designed to make great progress on a wide front, but to predict which individual area will deliver a new discovery tomorrow is impossible. In general, this is well understood by both parties, science and society; but when science is asked to solve a problem, its instinct is to start from fundamentals and proceed on its slow but inexorable timetable. When society—through its agent government—says "I need the answer now," the two systems have serious misunderstandings. Science, trying to be accommodating, frequently says, "I'll give you a progress report, but understand that we need more data to get a definitive answer." The "but" clause soon gets forgotten, so science gives an educated guess as to whether saccharin is carcinogenic, or dioxin is deadly poisonous, or the climate is warming, and later revises the first estimate, bewildering the public and making it distrustful of science. A report on cholesterol in the diet needs volunteers and those at high risk are the most likely to volunteer, but scientists know that preliminary reports for a high-risk group are helpful but should not be overgeneralized until a more normal group (and the more difficult to study) becomes the focus of study. The subject is too interesting to prevent premature publication and premature conclusions, but the new facts require revisions which lead the public to say "the scientists should make up their minds." At the frontier, scientists are individualists, not consensus groups, and science adds more facts and voices until a full understanding is approached asymptotically. The final value can be the truth at some level of detail but in some cases may simply reflect the exhaustion or exasperation of some of the participants.

In the course of a debate, not only do different scientists enter with different ideas, but new data are continuously uncovered. So science is not failing the public by changing its mind. Nor is it being irresponsible in volunteering a progress report. To refuse to give an educated guess to those who are paying the bill would be irresponsible unless the progress report is presented as though it were a final opinion. In a number of recent debates a premature release of a tentative conclusion became a congressional excuse for a final judgment, for example, in the case of the carcinogenicity of saccharine despite the inconclusiveness of the data.

The great discoveries of science are the result of a range of discoveries in which an initial notion was suggested, but the final understanding required lots of work. The societal problems of climate change, public health, economic efficiency, and so forth are even more complicated than the related pure science problems, and it should be expected that they would be equally prone to revision and updating.

A good example of this revisionism is reflected in a special series that ran in *The New York Times* the week of 21 March 1993, which reports that environmentalism is now showing a new trend toward cost-benefit analysis. The story gives an excellent account of excessive costs of some highly publicized risks and the past tendency of the Environmental Protection Agency to follow publicity rather than science in its approach to the environment. The change in sentiment is occurring because the evidence is accumulating that a "to hell with the cost" approach is impossibly expensive and the data on risks are now more definitive and less scary. Solid evidence can change minds, but getting the data requires time. Some scientists had explained that the early data were dubious, but they were ignored.

Scientists must assist in producing and explaining preliminary findings on scientific problems even if their instincts are to say "go away until I've solved the problem." And politicians must understand that progress reports should not be used as laws that are not allowed to be modified. The alternatives are that government makes hasty decisions based on third-rate scientific advice and scientists refuse to give any opinions. Distrust between the partners arises when each forgets that the other is operating in an uncomfortable mode—scientists being forced to give premature conclusions, government being forced to delay decisions until evidence is acquired. This "odd couple" of science and government has produced an unparalleled standard of living for its people. It will produce even more if each partner seeks common ground and gives credit to its partner for willingness to compromise its normal operating procedures and to contribute toward a common goal.

Daniel E. Koshland, Jr.

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SCIENTIFIC ASSESSMENT
OF
CLIMATE CHANGE

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WMO

The Policymakers' Summary
of the
Report of Working Group I
to the
Intergovernmental Panel on Climate Change

UNEP

PREFACE

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by our two organizations in 1988. Under the chairmanship of Professor Bert Bolin, the Panel was charged with:

(i) assessing the scientific information that is related to the various components of the climate change issue, such as emissions of major greenhouse gases and modification of the Earth's radiation balance resulting therefrom, and that needed to enable the environmental and socio-economic consequences of climate change to be evaluated, and

(ii) formulating realistic response strategies for the management of the climate change issue.

The Panel began its task by establishing Working Groups I, II and III respectively to:

(a) assess available scientific information on climate change,

(b) assess environmental and socio-economic impacts of climate change, and

(c) formulate response strategies.

It also established a Special Committee on the Participation of Developing Countries to promote, as quickly as possible, the full participation of developing countries in its activities.

This Policymakers' Summary of Working Group I should be read in conjunction with the rest of the IPCC first assessment report; the latter consists of the reports and policymakers' summaries of the three Working Groups and the Special Committee, and the IPCC overview and conclusions.

The Chairman of Working Group I, Dr John Houghton, and his Secretariat, have succeeded beyond measure in mobilizing the co-operation and enthusiasm of hundreds of scientists from all over the world. Their main report is of remarkable depth and breadth, and this Policymakers' Summary translates these complex scientific issues into language which is understandable to the non-specialist. We take this opportunity to congratulate and thank the Chairman for a job well done.

G.O.P. Obasi
Secretary-General
World Meteorological Organization

M.K. Tolba
Executive Director
United Nations Environment Programme

July 1990

SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE

FOREWORD

Many previous reports have addressed the question of climate change which might arise as a result of man's activities. In preparing the IPCC Scientific Assessment*, Working Group I has built on these, taking into account significant work undertaken and published since then. Particular attention is paid to what is known regarding the detail of climate change on a regional level.

In the preparation of the main Assessment most of the active scientists working in the field have been involved. One hundred and seventy scientists from 25 countries have contributed to it, either through participation in the twelve international workshops organized specially for the purpose or through written contributions. A further 200 scientists have been involved in the peer review of the draft report. This has helped to ensure a high degree of consensus amongst authors and reviewers regarding the results presented although, as in any developing scientific topic, there is a minority of views that are outside this consensus and which we have not been able to accommodate. The Policymakers' Summary was subject to a similar, wide, peer review, and the text was agreed at the final meeting of Working Group I in May 1990. They are therefore authoritative statements of the views of the international scientific community at this time.

It gives me pleasure to acknowledge the contributions of so many, in particular the Lead Authors, who have given freely of their expertise and time in the preparation of this report, and the modelling centres who have readily provided results. I would also like to thank the core team at the Meteorological Office, Bracknell, who were responsible for organizing most of the workshops and preparing the report, and the Departments of Environment and Energy in the United Kingdom who provided the necessary financial support.

I am confident that the Assessment and its Summary will provide the necessary firm scientific foundation for the forthcoming discussions and negotiations on the appropriate strategy for response and action regarding the issue of climate change. It is thus, I believe, a significant step forward in meeting what is potentially the greatest global environmental challenge facing mankind.

John Houghton
Chairman, IPCC Working Group I

Meteorological Office
Bracknell
United Kingdom

July 1990

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* Intergovernmental Panel on Climate Change, 1990.

Design and artwork by Meteorological Office Commercial Services.

Photographs supplied by Jonathan Walton and J.F.P. Galvin.

*Scientific Assessment of Climate Change, WMO/UNEP Intergovernmental Panel on Climate Change; Geneva (1990). Also published as, Climate Change: The IPCC Scientific Assessment; Houghton, J.T., G.J. Jenkins and J.J. Ephraums (Editors), Cambridge University Press, Cambridge, 1990.

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SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE

EXECUTIVE SUMMARY

We are certain of the following:

- there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be.

- emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

We calculate with confidence that:

- some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past, and is likely to remain so in the future.

- atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations to stabilize at a given level.

- the long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels; methane would require a 15–20% reduction.

Based on current model results, we predict:

- under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade); this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3°C before the end of the next century. The rise will not be steady because of the influence of other factors.

- under the other IPCC emission scenarios which assume progressively increasing levels of controls, rates of increase in global mean temperature of about 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C) and about 0.1°C per decade (Scenario D).

- that land surfaces warm more rapidly than the ocean, and high northern latitudes warm more than the global mean in winter.

- regional climate changes different from the global mean, although our confidence in the prediction of the detail of regional changes is low. For example, temperature increases in southern Europe and central North America are predicted to be higher than the global mean, accompanied on average by reduced summer precipitation and soil moisture. There are less consistent predictions for the tropics and the southern hemisphere.

- under the IPCC Business-as-Usual emissions scenario, an average rate of global mean sea level rise of about 6cm per decade over the next century (with an uncertainty range of 3–10cm per decade), mainly due to thermal expansion of the oceans and the melting of some land ice. The predicted rise is about 20cm in global mean sea level by 2030, and 65cm by the end of the next century. There will be significant regional variations.

There are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change, due to our incomplete understanding of:

- sources and sinks of greenhouse gases, which affect predictions of future concentrations
- clouds, which strongly influence the magnitude of climate change
- oceans, which influence the timing and patterns of climate change
- polar ice sheets which affect predictions of sea level rise

These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises.

Our judgement is that:

- Global mean surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years, with the five global mean warmest years being in the 1980s. Over the same period global sea level has increased by 10–20cm. These increases have not been smooth with time, nor uniform over the globe.
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.
- There is no firm evidence that climate has become more variable over the last few decades. However, with an increase in the mean temperature, episodes of high temperatures will most likely become more frequent in the future, and cold episodes less frequent.
- Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use by vegetation. The effect of warming on biological processes, although poorly understood, may increase the atmospheric concentrations of natural greenhouse gases.

To improve our predictive capability, we need:

- to **understand** better the various climate-related processes, particularly those associated with clouds, oceans and the carbon cycle
- to **improve** the systematic observation of climate-related variables on a global basis, and further investigate changes which took place in the past
- to **develop** improved models of the Earth's climate system
- to **increase** support for national and international climate research activities, especially in developing countries
- to **facilitate** international exchange of climate data

SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE

Introduction: what is the issue?

There is concern that human activities may be inadvertently changing the climate of the globe through the enhanced greenhouse effect, by past and continuing emissions of carbon dioxide and other gases which will cause the temperature of the Earth's surface to increase — popularly termed the "global warming". If this occurs, consequent changes may have a significant impact on society.

The purpose of the Working Group I report, as determined by the first meeting of IPCC, is to provide a scientific assessment of:

1) the factors which may affect climate change during the next century especially those which are due to human activity.

2) the responses of the atmosphere-ocean-land-ice system.

3) current capabilities of modelling global and regional climate changes and their predictability.

4) the past climate record and presently observed climate anomalies.

On the basis of this assessment, the report presents current knowledge regarding predictions of climate change (including sea level rise and the effects on ecosystems) over the next century, the timing of changes together with an assessment of the uncertainties associated with these predictions.

This Policymakers' Summary aims to bring out those elements of the main report which have the greatest relevance to policy formulation, in answering the following questions:

- What factors determine global climate?
- What are the greenhouse gases, and how and why are they increasing?
- Which gases are the most important?
- How much do we expect the climate to change?
- How much confidence do we have in our predictions?
- Will the climate of the future be very different?
- Have human activities already begun to change global climate?
- How much will the sea level rise?
- What will be the effects on ecosystems?
- What should be done to reduce uncertainties, and how long will this take?

This report is intended to respond to the practical needs of the policymaker. It is neither an academic review, nor a plan for a new research programme. Uncertainties attach to almost every aspect of the issue, yet policymakers are looking for clear guidance from scientists; **hence authors have been asked to provide their best-estimates wherever possible**, together with an assessment of the uncertainties.

This report is a summary of our understanding in 1990. Although continuing research will deepen this understanding and require the report to be updated at frequent intervals, basic conclusions concerning the reality of the enhanced greenhouse effect and its potential to alter global climate are unlikely to change significantly. Nevertheless, the complexity of the system may give rise to surprises.

What factors determine global climate?

There are many factors, both of natural and human origin, that determine the climate of the Earth. We look first at those which are natural, and then see how human activities might contribute.

What natural factors are important?

The driving energy for weather and climate comes from the Sun. The Earth intercepts solar radiation (including that in the short-wave, visible, part of the spectrum); about a third of it is reflected, the rest is absorbed by the different components (atmosphere, ocean, ice, land and biota) of the climate system. The energy absorbed from solar radiation is balanced (in the long term) by outgoing radiation from the Earth and atmosphere; this terrestrial radiation takes the form of long-wave invisible infra-red energy, and its magnitude is determined by the temperature of the Earth–atmosphere system.

There are several natural factors which can change the balance between the energy absorbed by the Earth and that emitted by it in the form of long-wave infra-red radiation; these factors cause the **radiative forcing** on climate. The most obvious of these is a change in the output of energy from the Sun. There is direct evidence of such variability over the 11-year solar cycle, and longer-period changes may also occur. Slow variations in the Earth's orbit affect the seasonal and latitudinal distribution of solar radiation; these were probably responsible for initiating the ice ages.

One of the most important factors is the **greenhouse effect**; a simplified explanation of which is as follows. Short-wave solar radiation can pass through the clear atmosphere relatively unimpeded. But long-wave terrestrial radiation emitted by the warm surface of the Earth is partially absorbed and then re-emitted by a number of trace gases in the cooler atmosphere above. Since, on average, the outgoing long-wave radiation balances the incoming solar radiation, both the atmosphere and the surface will be warmer than they would be without the greenhouse gases.

The main natural greenhouse gases are not the major constituents, nitrogen and oxygen, but water vapour (the biggest contributor), carbon dioxide, methane, nitrous oxide, and ozone in the troposphere (the lowest 10–15km of the atmosphere) and stratosphere.

Aerosols (small particles) in the atmosphere can also affect climate because they can reflect and absorb radiation. The most important natural perturbations result from explosive volcanic eruptions which affect concentrations in the lower stratosphere. Lastly, the climate has its own **natural variability** on all time-scales and changes occur without any external influence.

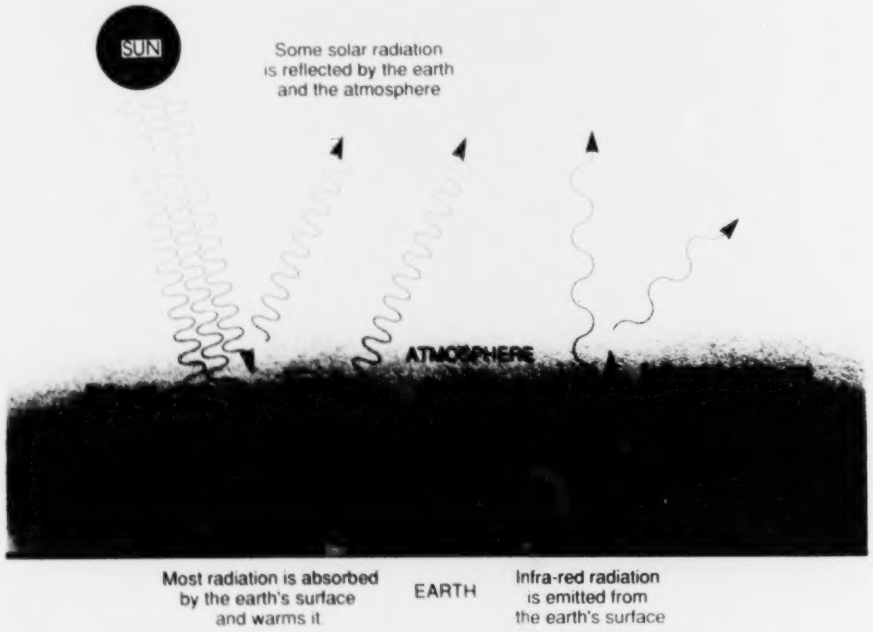
How do we know that the natural greenhouse effect is real?

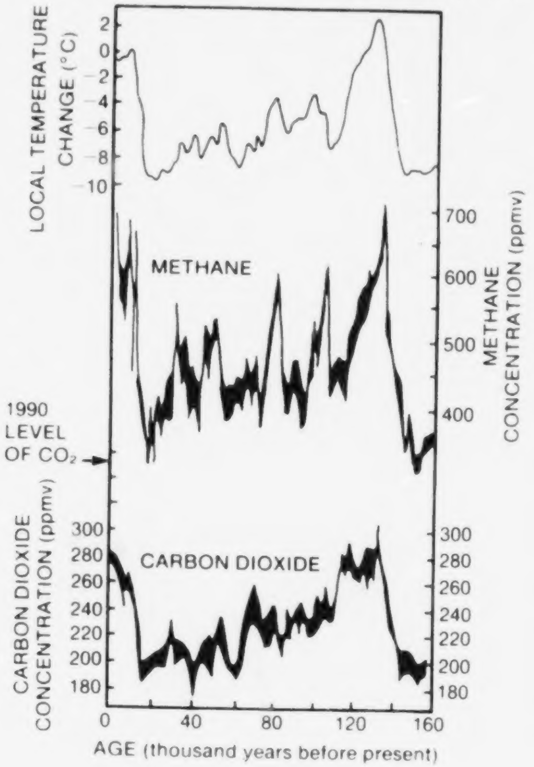
The greenhouse effect is real; it is a well understood effect, based on established scientific principles. We know that the greenhouse effect works in practice, for several reasons.

Firstly, the mean temperature of the Earth's surface is already warmer by about 33°C (assuming the same reflectivity of the earth) than it would be if the natural greenhouse gases were not present. Satellite observations of the radiation emitted from the Earth's surface and through the atmosphere demonstrate the effect of the greenhouse gases.

Secondly, we know the composition of the atmospheres of Venus, Earth and Mars are very different, and their surface temperatures are in general agreement with greenhouse theory. Thirdly, measurements from ice cores going back 160,000 years show that the Earth's temperature closely paralleled the amount of carbon dioxide and methane in the atmosphere. Although we do not know the details of cause and effect, calculations indicate that changes in these greenhouse gases

A simplified diagram illustrating the greenhouse effect.


SUN
Some solar radiation is reflected by the earth and the atmosphere
ATMOSPHERE
Most radiation is absorbed by the earth's surface and warms it
EARTH
Infra-red radiation is emitted from the earth's surface



Analysis of air trapped in Antarctic ice cores shows that methane and carbon dioxide concentrations were closely correlated with the local temperature over the last 160,000 years. Present-day concentrations of carbon dioxide are indicated.

were part, but not all, of the reason for the large (5–7 °C) global temperature swings between ice ages and interglacial periods.

How might human activities change global climate?

Naturally occurring greenhouse gases keep the Earth warm enough to be habitable. By increasing their concentrations, and by adding new greenhouse gases like chlorofluorocarbons (CFCs), humankind is capable of raising the global-average annual-mean surface-air temperature (which, for simplicity, is referred to as the "global temperature"), although we are uncertain about the rate at which this will occur. Strictly, this is an **enhanced** greenhouse effect – above that occurring due to natural greenhouse gas concentrations; the word "enhanced" is usually omitted, but it should not be forgotten. Other changes in climate are expected to result, for example changes in precipitation, and a global warming will cause sea levels to rise; these are discussed in more detail later.

There are other human activities which have the potential to affect climate. A change in the albedo (reflectivity) of the land, brought about by **desertification or deforestation** affects the amount of solar energy absorbed at the Earth's surface. Human-made **aerosols**, from sulphur emitted largely in fossil fuel combustion, can modify clouds and this may act to lower temperatures. Lastly, changes in **ozone in the stratosphere** due to CFCs may also influence climate.

What are the greenhouse gases and why are they increasing?

We are certain that the concentrations of greenhouse gases in the atmosphere have changed naturally on ice-age time-scales, and have been increasing since pre-industrial times due to human activities. The table opposite summarizes the present and pre-industrial abundances, current rates of change and present atmospheric lifetimes of greenhouse gases influenced by human activities. Carbon dioxide, methane, and nitrous oxide all have significant natural and human sources, while the CFCs are only produced industrially.

Two important greenhouse gases, water vapour and ozone, are not included in the table opposite. Water vapour has the largest greenhouse effect, but its concentration in the troposphere is determined internally within the climate system, and, on a global scale, is not affected by human sources and sinks. Water vapour will increase in response to global warming and further enhance it; this process is included in climate models. The concentration of ozone is changing both in the stratosphere and the troposphere due to human activities, but it is difficult to quantify the changes from present observations.

For a thousand years prior to the industrial revolution, abundances of the greenhouse gases were relatively constant. However, as the world's population increased, as the world became more industrialized and as agriculture developed, the abundances of the greenhouse gases increased markedly. The figures on page 9 illustrate this for carbon dioxide, methane, nitrous oxide and CFC-11.

Since the industrial revolution the combustion of fossil fuels and deforestation have led to an increase of 26% in carbon dioxide concentration in the atmosphere. We know the magnitude of the present day fossil-fuel source, but the input from deforestation cannot be estimated accurately. In addition, although about half of the emitted carbon

SUMMARY OF KEY GREENHOUSE GASES AFFECTED BY HUMAN ACTIVITIES

	Carbon Dioxide	Methane	CFC-11	CFC-12	Nitrous Oxide
Atmospheric concentration	ppmv	ppmv	pptv	pptv	ppbv
Pre-industrial (1750–1800)	280	0.8	0	0	288
Present day (1990)	353	1.72	280	484	310
Current rate of change per year	1.8 (0.5%)	0.015 (0.9%)	9.5 (4%)	17 (4%)	0.8 (0.25%)
Atmospheric lifetime (years)	(50–200)*	10	65	130	150

ppmv = parts per million by volume;
ppbv = parts per billion (thousand million) by volume;
pptv = parts per trillion (million million) by volume.
*The way in which CO_2 is absorbed by the oceans and biosphere is not simple and a single value cannot be given; refer to the main report for further discussion.

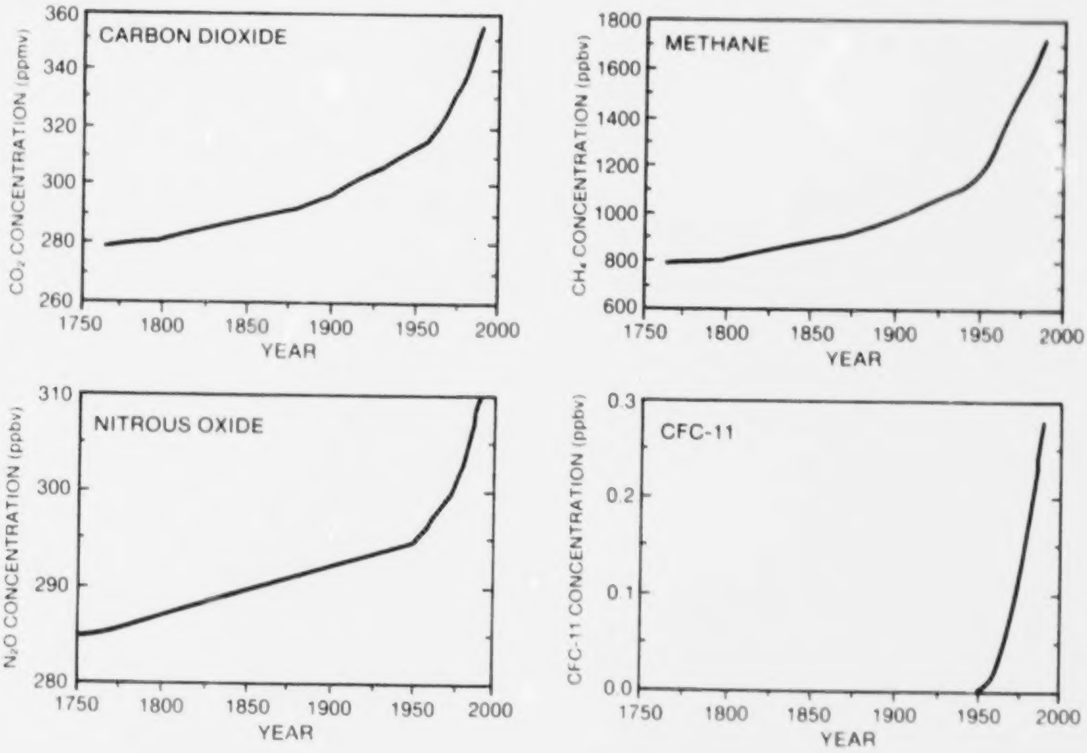
dioxide stays in the atmosphere, we do not know well how much of the remainder is absorbed by the oceans and how much by terrestrial biota. Emissions of chlorofluorocarbons, used as aerosol propellants, solvents, refrigerants and foam-blowing agents, are also well known; they were not present in the atmosphere before their invention in the 1930s.

The sources of methane and nitrous oxide are less well known. Methane concentrations have more than doubled because of rice production, cattle rearing, biomass burning, coal mining and venting of natural gas; also, fossil fuel combustion may have also contributed through chemical reactions in the atmosphere which reduce the rate of removal of methane. Nitrous oxide has increased by about 8% since pre-industrial times, presumably due to human activities; we are unable to specify the sources, but it is likely that agriculture plays a part.

The effect of ozone on climate is strongest in the upper troposphere and lower stratosphere. Model calculations indicate that ozone in the upper troposphere should have increased due to human-made emissions of nitrogen oxides, hydrocarbons and carbon monoxide. While at ground level, ozone has increased in the northern hemisphere in response to these emissions, observations are insufficient to confirm the expected increase in the upper troposphere. The lack of adequate observations prevents us from accurately quantifying the climatic effect of changes in tropospheric ozone.

In the lower stratosphere at high southern latitudes, ozone has decreased considerably due to the effects of CFCs, and there are indications of a global-scale decrease which, while not understood, may also be due to CFCs. These observed decreases should act to cool the Earth's surface, thus providing a small offset to the predicted warming produced by the other greenhouse gases. Further reductions in lower stratospheric ozone are possible during the next few decades as the atmospheric abundances of CFCs continue to increase.

SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE



Concentrations of carbon dioxide and methane after remaining relatively constant up to the 18th century, have risen sharply since then due to man's activities. Concentrations of nitrous oxide have increased since the mid-18th century, especially in the last few decades. CFCs were not present in the atmosphere before the 1930s.

Concentrations, lifetimes and stabilization of the gases

In order to calculate the atmospheric concentrations of carbon dioxide which will result from human-made emissions we use computer models which incorporate details of the emissions and which include representations of the transfer of carbon dioxide between the atmosphere, oceans and terrestrial biosphere. For the other greenhouse gases, models which incorporate the effects of chemical reactions in the atmosphere are employed.

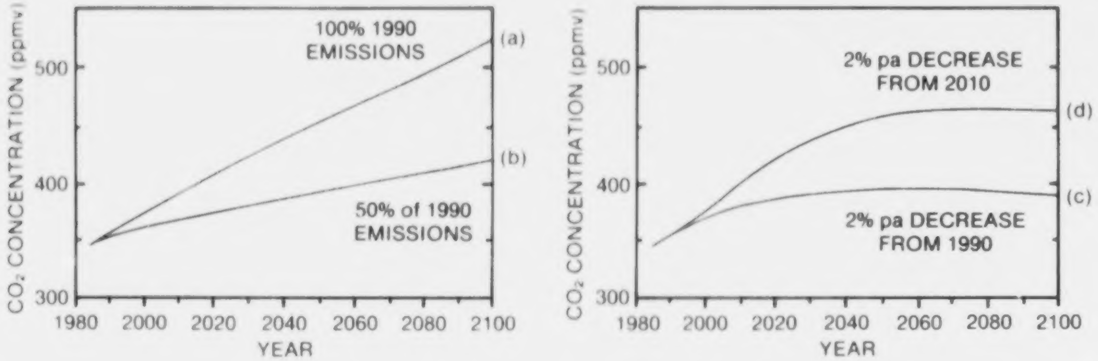
The atmospheric lifetimes of the gases are determined by their sources and sinks in the oceans, atmosphere and biosphere. Carbon dioxide, chlorofluorocarbons and nitrous oxide are removed only slowly from the atmosphere and hence, following a change in emissions, their atmospheric concentrations take decades to centuries to adjust fully. Even if all human-made emissions of carbon dioxide were halted in the year 1990, about half of the increase in carbon dioxide concentration caused by human activities would still be evident by the year 2100.

In contrast, some of the CFC substitutes and methane have relatively short atmospheric lifetimes so that their atmospheric concentrations respond fully to emission changes within a few decades.

To illustrate the emission–concentration relationship clearly, the effect of hypothetical changes in carbon dioxide fossil fuel emissions is shown on page 10. (a) continuing global emissions at 1990 levels; (b) halving of emissions in 1990; (c) reductions in emissions of 2% per year (p.a.) from 1990 and (d) a 2% p.a. increase from 1990–2010 followed by a 2% p.a. decrease from 2010.

Continuation of present-day emissions are committing us to increased future concentrations, and the longer emissions continue to increase, the greater would reductions have to be to stabilize at a given level. If there are critical concentration levels that should not be exceeded, then the earlier emission reductions are made the more effective they are.

SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE



The relationship between hypothetical fossil fuel emissions of carbon dioxide and its concentration in the atmosphere is shown in the case where (a) emissions continue at 1990 levels, (b) emissions are reduced by 50% in 1990 and continue at that level, (c) emissions are reduced by 2% p.a. from 1990, and (d) emissions, after increasing by 2% p.a. until 2010, are then reduced by 2% p.a. thereafter.

The term "**atmospheric stabilization**" is often used to describe the limiting of the concentration of the greenhouse gases at a certain level. The amount by which human-made emissions of a greenhouse gas must be reduced in order to stabilize at present-day concentrations, for example, is shown in the box below. For most gases the reductions would have to be substantial.

How will greenhouse gas abundances change in the future?

We need to know future greenhouse gas concentrations in order to estimate future climate change. As already mentioned, these concentrations depend upon the magnitude of human-made emissions and on how changes in climate and other environmental conditions may influence the biospheric processes that control the exchange of natural greenhouse gases, including carbon dioxide and methane, between the atmosphere, oceans and terrestrial biosphere — the greenhouse gas "feedbacks".

Four scenarios of future human-made emissions were developed by Working Group III. The first of these assumes that few or no steps are taken to limit greenhouse gas emissions, and this is therefore termed Business-as-Usual (BaU). (It should be noted that an aggregation of national forecasts of emissions of carbon dioxide and methane to the year 2025 undertaken by Working Group III resulted in global emissions 10–20% higher than in the BaU scenario.) The other three scenarios assume that progressively increasing levels of controls reduce the growth of

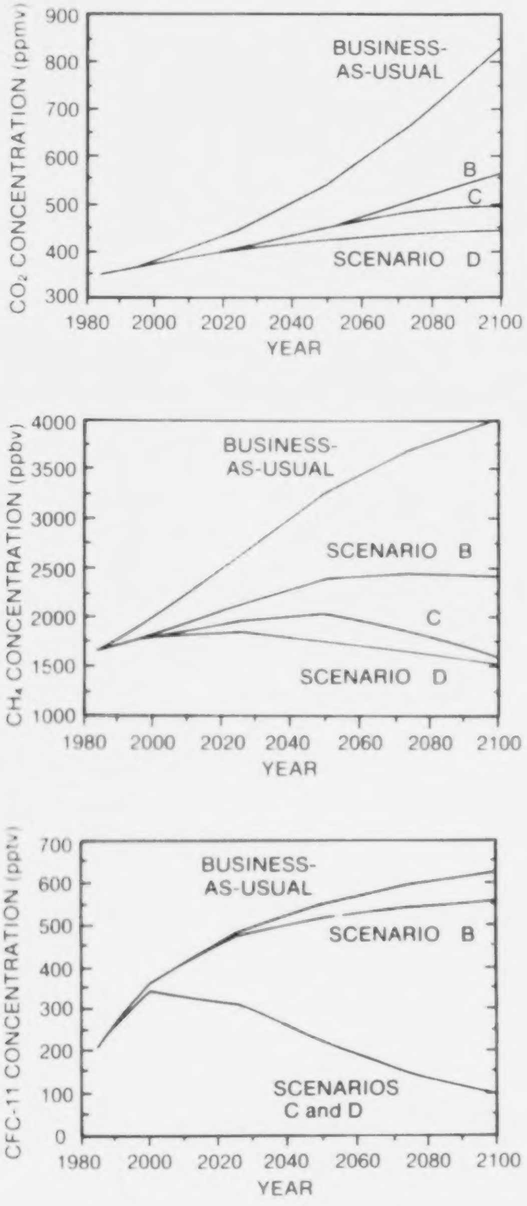
STABILIZATION OF ATMOSPHERIC CONCENTRATIONS

Reductions in the human-made emissions of greenhouse gases required to stabilize concentrations at present-day levels:

Carbon Dioxide	<60%
Methane	15–20%
Nitrous Oxide	70–80%
CFC-11	70–75%
CFC-12	75–85%
HCFC-22	40–50%

Note that the stabilization of each of these gases would have different effects on climate, as explained in the next section.

emissions; these are referred to as scenarios B, C, and D. They are briefly described in the Annex. Future concentrations of some of the greenhouse gases which would arise from these emissions are shown below.



Atmospheric concentrations of carbon dioxide, methane and CFC-11 resulting from the four IPCC emissions scenarios.

Greenhouse gas feedbacks

Some of the possible feedbacks which could significantly modify future greenhouse gas concentrations in a warmer world are discussed in the following paragraphs.

The net emissions of carbon dioxide from terrestrial ecosystems will be elevated if higher temperatures increase respiration at a faster rate than photosynthesis, or if plant populations, particularly large forests, cannot adjust rapidly enough to changes in climate.

A net flux of carbon dioxide to the atmosphere may be particularly evident in warmer conditions in tundra and boreal regions where there are large stores of carbon. The opposite is true if higher abundances of carbon dioxide in the atmosphere enhance the productivity of natural ecosystems, or if there is an increase in soil moisture which can be expected to stimulate plant growth in dry ecosystems and to increase the storage of carbon in tundra peat. The extent to which ecosystems can sequester increasing atmospheric carbon dioxide remains to be quantified.

If the oceans become warmer, their net uptake of carbon dioxide may decrease because of changes in (i) the chemistry of carbon dioxide in sea-water, (ii) biological activity in surface waters, and (iii) the rate of exchange of carbon dioxide between the surface layers and the deep ocean. This last depends upon the rate of formation of deep water in the ocean which, in the North Atlantic for example, might decrease if the salinity decreases as a result of a change in climate.

Methane emissions from natural wetlands and rice paddies are particularly sensitive to temperature and soil moisture. Emissions are significantly larger at higher temperatures and with increased soil moisture; conversely, a decrease in soil moisture would result in smaller emissions. Higher temperatures could increase the emissions of methane at high northern latitudes from decomposable organic matter trapped in permafrost and methane hydrates.

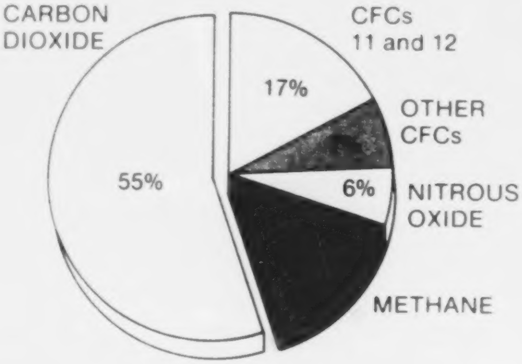
As illustrated earlier, ice-core records show that methane and carbon dioxide concentrations changed in a similar sense to temperature between ice ages and interglacials.

Although many of these feedback processes are poorly understood, it seems likely that, overall, they will act to increase, rather than decrease, greenhouse gas concentrations in a warmer world.

Which gases are the most important?

We are certain that increased greenhouse gas concentrations increase radiative forcing. We can calculate the forcing with much more confidence than the climate change that results because the former avoids the need to evaluate a number of poorly understood atmospheric responses. We then have a base from which to calculate the relative effect on climate of an increase in **concentration** of each gas in the present-day atmosphere, both in absolute terms and relative to carbon dioxide. These relative effects span a wide range; methane is about 21 times more effective, molecule-for-molecule, than carbon dioxide, and CFC-11 about 12,000 times more effective. On a kilogram-per-kilogram basis, the equivalent values are 58 for methane and about 4,000 for CFC-11, both relative to carbon dioxide. Values for other greenhouse gases are to be found in the full report.

The total radiative forcing at any time is the sum of those from the individual greenhouse gases. We show in the figure below how this quantity has changed in the past (based on observations of greenhouse gases) and how it might change in the future (based on the four IPCC emissions scenarios). For simplicity, we can express total forcing in terms of the amount of carbon dioxide which would give that forcing; this is termed the **equivalent carbon dioxide concentration**. Greenhouse gases have increased since pre-industrial times (the mid-18th century) by an amount that is radiatively equivalent to about a 50% increase in carbon dioxide, although carbon dioxide itself has risen by only 26%; other gases have made up the rest.



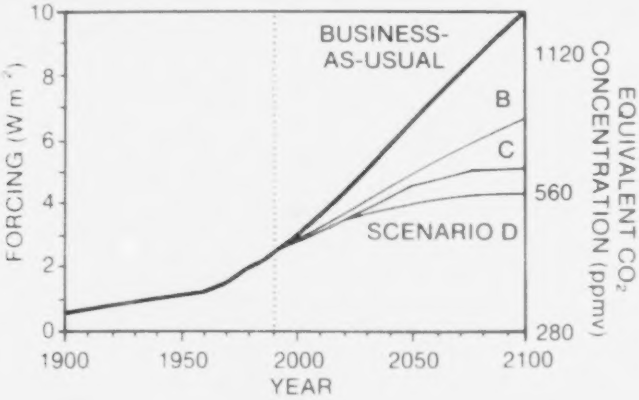
The contribution from each of the human-made greenhouse gases to the change in radiative forcing from 1980 to 1990. The contribution from ozone may also be significant, but cannot be quantified at present.

The contributions of the various gases to the total increase in climate forcing during the 1980s is shown above as a pie diagram; carbon dioxide is responsible for about half the decadal increase. (Ozone, the effects of which may be significant, is not included.)

How can we evaluate the effect of different greenhouse gases?

To evaluate possible policy options, it is useful to know the relative radiative effect (and, hence, potential climate effect) of equal emissions of each of the greenhouse gases. The concept of relative **Global Warming Potentials (GWP)** has been developed to take into account the differing times that gases remain in the atmosphere.

Increase in radiative forcing since the mid-18th century, and predicted to result from the four IPCC emissions scenarios, also expressed as equivalent carbon dioxide concentrations.



GLOBAL WARMING POTENTIALS

The warming effect of an emission of 1kg of each gas relative to that of carbon dioxide.
These figures are best estimates calculated on the basis of the present-day atmospheric composition

	Time Horizon		
	20 yr	100 yr	500 yr
Carbon dioxide	1	1	1
Methane (including indirect)	63	21	9
Nitrous oxide	270	290	190
CFC-11	4500	3500	1500
CFC-12	7100	7300	4500
HCFC-22	4100	1500	510

Global Warming Potentials for a range of CFCs and potential replacements are given in the full text

This index defines the time-integrated warming effect due to an instantaneous release of unit mass (1kg) of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide. The relative importances will change in the future as atmospheric composition changes because, although radiative forcing increases in direct proportion to the concentration of CFCs, changes in the other greenhouse gases (particularly carbon dioxide) have an effect on forcing which is much less than proportional.

The GWPs in the table above are shown for three time-horizons, reflecting the need to consider the cumulative effects on climate over various time-scales. The longer time-horizon is appropriate for the cumulative effect; the shorter time-scale will indicate the response to emission changes in the short term. There are a number of practical difficulties in devising and calculating the values of the GWPs, and the values given here should be considered as preliminary. In addition to these direct effects, there are indirect effects of human-made emissions arising from chemical reactions between the various constituents. The indirect effects on stratospheric water vapour, carbon dioxide and tropospheric ozone have been included in these estimates.

THE RELATIVE CUMULATIVE CLIMATE EFFECT OF 1990 MAN-MADE EMISSIONS

	GWP (100 yr horizon)	1990 emissions (Tg)	Relative contribution over 100 yr
Carbon dioxide	1	26000†	61%
Methane*	21	300	15%
Nitrous oxide	290	6	4%
CFCs	Various	0.9	11%
HCFC-22	1500	0.1	0.5%
Others*	Various		8.5%

*These values include the indirect effect of these emissions on other greenhouse gases via chemical reactions in the atmosphere. Such estimates are highly model dependent and should be considered preliminary and subject to change. The estimated effect of ozone is included under "others". The gases included under "others" are given in the full report.

†26000 Tg (teragrams) of carbon dioxide = 7 000 Tg (=7 Gt) of carbon

CHARACTERISTICS OF THE GREENHOUSE GASES

GAS	MAJOR CONTRIBUTOR?	LONG LIFETIME?	SOURCE KNOWN?
Carbon dioxide	yes	yes	yes
Methane	yes	no	semi-quantitatively
Nitrous oxide	not at present	yes	qualitatively
CFCs	yes	yes	yes
HCFCs etc.	not at present	mainly no	yes
Ozone	possibly	no	qualitatively

The table indicates, for example, that the effectiveness of methane in influencing climate will be greater in the first few decades after release, whereas emission of the longer-lived nitrous oxide will affect climate for a much longer time. The lifetimes of the proposed CFC replacements range from 1 to 40 years; the longer-lived replacements are still potentially effective as agents of climate change. One example of this, HCFC-22 (with a 15-year lifetime), has a similar effect (when released in the same amount) as CFC-11 on a 20-year time-scale; but less over a 500-year time-scale.

Although carbon dioxide is the least effective greenhouse gas per kilogram emitted, its contribution to global warming, which depends on the product of the GWP and the amount emitted, is largest. In the example in the lower box on page 12, the effect over 100 years of emissions of greenhouse gases in 1990 are shown relative to carbon dioxide. This is illustrative; to compare the effect of different emission projections we have to sum the effect of emissions made in future years.

There are other technical criteria which may help policymakers to decide, in the event of emissions reductions being deemed necessary, which gases should be considered. Does the gas contribute in a major way to current, and future, climate forcing? Does it have a long lifetime, so earlier reductions in emissions would be more effective than those made later? And are its sources and sinks well enough known to decide which could be controlled in practice? The table above illustrates these factors.

How much do we expect climate to change?

It is relatively easy to determine the direct effect of the increased radiative forcing due to increases in greenhouse gases. However, as climate begins to warm, various processes act to amplify (through positive feedbacks) or reduce (through negative feedbacks) the warming. The main feedbacks which have been identified are due to changes in water vapour, sea-ice, clouds and the oceans.

The best tools we have which take the above feedbacks into account (but do not include greenhouse gas feedbacks) are three-dimensional mathematical models of the climate system (atmosphere ocean ice land), known as General Circulation Models (GCMs). They synthesize our knowledge of the physical and dynamical processes in the overall system and allow for the complex interactions between the various components. However, in their current state of development, the descriptions of many of the processes involved are comparatively crude. Because of this, considerable uncertainty is attached to these predictions of climate change, which is reflected in the range of values given; further details are given in a later section.

The estimates of climate change presented here are based on

i) the "best estimate" of equilibrium climate sensitivity (i.e. the equilibrium temperature change due to a doubling of carbon dioxide in the atmosphere) obtained from model simulations, feedback analyses and observational considerations (see later box: "What tools do we use…?")

ii) a "box diffusion upwelling" ocean atmosphere climate model which translates the greenhouse forcing into the evolution of the temperature response for the prescribed climate sensitivity. (This simple model has been calibrated against more complex ocean atmosphere coupled GCMs for situations where the more complex models have been run).

How quickly will global climate change?

a. If emissions follow a Business-as-Usual pattern

Under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, the average rate of increase of global mean temperature during the next century is estimated to be about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C). This will result in a likely increase in global mean temperature of about 1°C above the present value (about 2°C above that in the pre-industrial period) by 2025 and 3°C above today's (about 4°C above pre-industrial) before the end of the next century.

The projected temperature rise out to the year 2100, with high, low and best-estimate climate responses, is shown in the diagram below. Because of other factors which influence climate, we would not expect the rise to be a steady one.

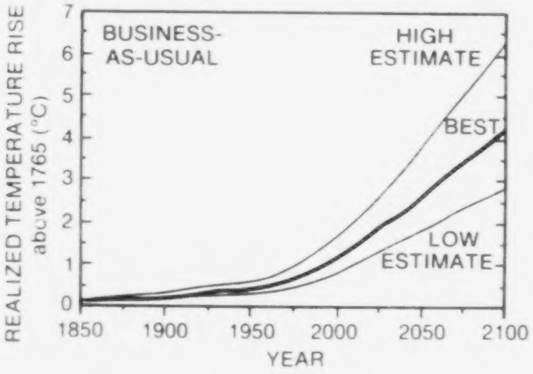
The temperature rises shown above are **realized** temperatures; at any time we would also be **committed** to a further temperature rise toward the equilibrium temperature (see box: "Equilibrium and realized climate change"). For the BaU "best-estimate" case in the year 2030, for example, a further 0.9°C rise would be expected, about 0.2°C of which would be realized by 2050 (in addition to changes due to further greenhouse gas increases); the rest would become apparent in decades or centuries.

Even if we were able to stabilize emissions of each of the greenhouse gases at present-day levels from now on, the temperature is predicted to rise by about 0.2°C per decade for the first few decades.

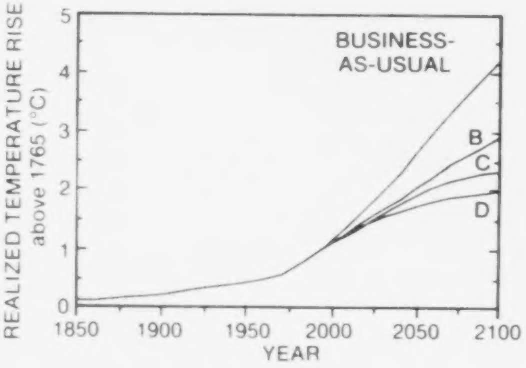
The global warming, will also lead to increased global average precipitation and evaporation of a few per cent by 2030. Areas of sea-ice and snow are expected to diminish.

b. If emissions are subject to controls

Under the other IPCC emission scenarios which assume progressively increasing levels of controls, average rates of increase in global mean temperature over the next century are estimated to be about 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C) and about 0.1°C per decade (Scenario D). The results are illustrated below with the Business-as-Usual case for comparison. Only the best-estimate of the temperature rise is shown in each case. The indicated range of uncertainty in global temperature rise given above reflects a subjective assessment of uncertainties in the calculation of climate response, but does not include those due to the transformation of emissions to concentrations, nor the effects of greenhouse gas feedbacks.



Simulation of the increase in global mean temperature from 1850 to 1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the Business-as-Usual emissions.



Simulations of the increase in global mean temperature from 1850 to 1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the IPCC Scenario B, C and D emissions, with the Business-as-Usual case for comparison.

What tools do we use to predict future climate, and how do we use them?

The most highly developed tool which we have to predict future climate is known as a **general circulation model or GCM.** These models are based on the laws of physics and use descriptions in simplified physical terms (called parametrizations) of the smaller-scale processes such as those due to clouds and deep mixing in the ocean. In a climate model an atmospheric component, essentially the same as a weather prediction model, is coupled to a model of the ocean, which can be equally complex.

Climate forecasts are derived in a different way from weather forecasts. A weather prediction model gives a description of the atmosphere's state up to 10 days or so ahead, starting from a detailed description of an initial state of the atmosphere at a given time. Such forecasts describe the movement and development of large weather systems, though they cannot represent very small-scale phenomena; for example, individual shower clouds.

To make a climate forecast, the climate model is first run for a few (simulated) decades. The statistics of the model's output is a description of the model's simulated climate which, if the model is a good one, will bear a close resemblance to the climate of the real atmosphere and ocean. The above exercise is then repeated with increasing concentrations of the greenhouse gases in the model. The differences between the statistics of the two simulations (for example in mean temperature and interannual variability) provide an estimate of the accompanying climate change.

The long-term change in **surface air temperature** following a doubling of carbon dioxide (referred to as the **climate sensitivity**) is generally used as a bench-mark to compare models. The range of results from model studies is 1.9 to 5.2°C. Most results are close to 4.0°C but recent studies using a more detailed but not necessarily more accurate representation of cloud processes give results in the lower half of this range. Hence the models results do not justify altering the previously accepted range of 1.5 to 4.5°C.

Although scientists are reluctant to give a single best estimate in this range, it is necessary for the presentation of climate predictions for a choice of best estimate to be made. Taking into account the model results, together with observational evidence over the last century which is suggestive of the climate sensitivity being in the lower half of the range (see section: "Has man already begun to change the global climate?" on page 20) a value of climate sensitivity of 2.5°C has been chosen as the best estimate.

In this Assessment, we have also used much simpler models, which simulate the behaviour of GCMs, to make predictions of the evolution with time of global temperature from a number of emission scenarios. These so-called box-diffusion models contain highly simplified physics but give similar results to GCMs when globally averaged.

A completely different, and potentially useful, way of predicting patterns of future climate is to search for periods in the past when the global mean temperatures were similar to those we expect in future, and then use the past spatial patterns as **analogues** of those which will arise in the future. For a good analogue, it is also necessary for the forcing factors (for example, greenhouse gases, orbital variations) and other conditions (for example, ice cover, topography, etc.) to be similar; direct comparisons with climate situations for which these conditions do not apply cannot be easily interpreted. Analogues of future greenhouse-gas-changed climates have not been found.

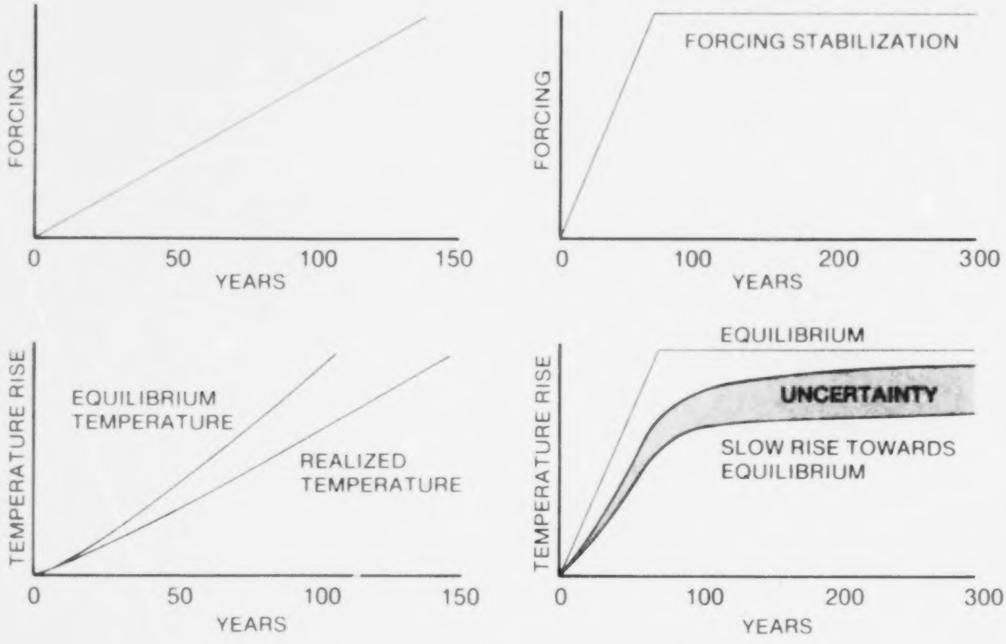
We cannot therefore advocate the use of palaeoclimates as predictions of regional climate change due to future increases in greenhouse gases. However, palaeoclimatological information can provide useful insights into climate processes, and can assist in the validation of climate models.

Equilibrium and realized climate change

When the radiative forcing on the earth–atmosphere system is changed, for example by increasing greenhouse gas concentrations, the atmosphere will try to respond (by warming) immediately. But the atmosphere is closely coupled to the oceans, so in order for the air to be warmed by the greenhouse effect, the oceans also have to be warmed; because of their thermal capacity this takes decades or centuries. This exchange of heat between atmosphere and ocean will act to slow down the temperature rise forced by the greenhouse effect.

In a hypothetical example where the concentration of greenhouse gases in the atmosphere, following a period of constancy, rises suddenly to a new level and remains there, the radiative forcing would also rise rapidly to a new level. This increased radiative forcing would cause the atmosphere and oceans to warm, and eventually come to a new, stable, temperature. A commitment to this **equilibrium** temperature rise is incurred as soon as the greenhouse gas concentration changes. But at any time before equilibrium is reached, the actual temperature will have risen by only part of the equilibrium temperature change, known as the **realized** temperature change.

Models predict that, for the present-day case of an increase in radiative forcing which is approximately steady, the realized temperature rise at any time is about 50% of the committed temperature rise if the climate sensitivity (the response to a doubling of carbon dioxide) is 4.5°C and about 80% if the climate sensitivity is 1.5°C. If the forcing were then held constant, temperatures would continue to rise slowly, but it is not certain whether it would take decades or centuries for most of the remaining rise to equilibrium to occur.



What will be the patterns of climate change by 2030?

Knowledge of the global mean warming and change in precipitation is of limited use in determining the impacts of climate change, for instance on agriculture. For this we need to know changes regionally and seasonally.

Models predict that surface air will warm faster over land than over oceans, and a minimum of warming will occur around Antarctica and in the northern North Atlantic region.

There are some continental-scale changes which are consistently predicted by the highest-resolution models and for which we understand the physical reasons. The warming is predicted to be 50–100% greater than the global mean in high northern latitudes in winter, and substantially smaller than the global mean in regions of sea-ice in summer. Precipitation is predicted to increase on average in middle and high latitude continents in winter (by some 5–10% over 35–55°N).

Five regions, each a few million square kilometres in area and representative of different climatological regimes, were selected by IPCC for particular study. In the box on page 18 are given the changes in temperature, precipitation and soil moisture, which are predicted to occur by 2030 on the Business-as-Usual scenario, as an average over each of the five regions. There may be considerable variations within the regions. In general, confidence in these regional estimates is low, especially for the changes in precipitation and soil moisture, but they are examples of our best estimates. We cannot yet give reliable regional predictions at the smaller scales demanded for impacts assessments.

How will climate extremes and extreme events change?

Changes in the variability of weather and the frequency of extremes will generally have more impact than changes in the mean climate at a particular location. With the possible exception of an increase in the number of intense showers, there is no clear evidence that weather variability will change in the future. In the case of temperatures, assuming no change in variability, but with a modest increase in the mean, the number of days with temperatures above a given value at the high end of the distribution will increase substantially. On the same assumptions, there will be a decrease in days with temperatures at the low end of the distribution. So the number of very hot days or frosty nights can be substantially changed without any change in the variability of the weather. The number of days with a minimum threshold amount of soil moisture (for viability of a certain crop, for example) would be even more sensitive to changes in average precipitation and evaporation.

If the large-scale weather regimes, for instance depression tracks or anticyclones, shift their position, this would effect the variability and extremes of weather at a particular location, and could have a major effect. However, we do not know if, or in what way, this will happen.

Will storms increase in a warmer world?

Storms can have a major impact on society. Will their frequency, intensity or location increase in a warmer world?

Tropical storms, such as typhoons and hurricanes, only develop at present over seas that are warmer than about 26°C. Although the area of sea having temperatures over this critical value will increase as the globe warms, the critical temperature itself may increase in a warmer world. Although the theoretical maximum intensity is expected to increase with temperature, climate models give no consistent indication whether tropical storms will increase or decrease in frequency or intensity as climate changes; neither is there any evidence that this has occurred over the past few decades.

Mid-latitude storms, such as those which track across the North Atlantic and North Pacific, are driven by the equator-to-pole temperature contrast. As this contrast will probably be weakened in a warmer world (at least in the northern hemisphere), it might be argued that mid-latitude storms will also weaken or change their tracks, and there is some indication of a general reduction in day-to-day variability in the mid-latitude storm tracks in winter in model simulations, though the pattern of changes vary from model to model. Present models do not resolve smaller-scale disturbances, so it will not be possible to assess changes in storminess until results from higher-resolution models become available in the next few years.

Climate change in the longer term

The foregoing calculations have focused on the period up to the year 2100; it is clearly more difficult to make calculations for years beyond 2100. However, while the timing of a predicted increase in global temperatures has substantial uncertainties, the prediction that an increase will eventually occur is more certain. Furthermore, some model calculations that have been extended beyond

ESTIMATES FOR CHANGES BY 2030

(IPCC Business-as-Usual scenario; changes from **pre-industrial**)

The numbers given below are based on high-resolution models, scaled to be consistent with our best estimate of global mean warming of 1.8°C by 2030. For values consistent with other estimates of global temperature rise, the numbers below should be reduced by 30% for the low estimate or increased by 50% for the high estimate. Precipitation estimates are also scaled in a similar way.

Confidence in these regional estimates is low

Central North America (35°–50°N 85°–105°W)
The warming varies from 2 to 4°C in winter and 2 to 3°C in summer. Precipitation increases range from 0 to 15% in winter whereas there are decreases of 5 to 10% in summer. Soil moisture decreases in summer by 15 to 20%.

[redacted]

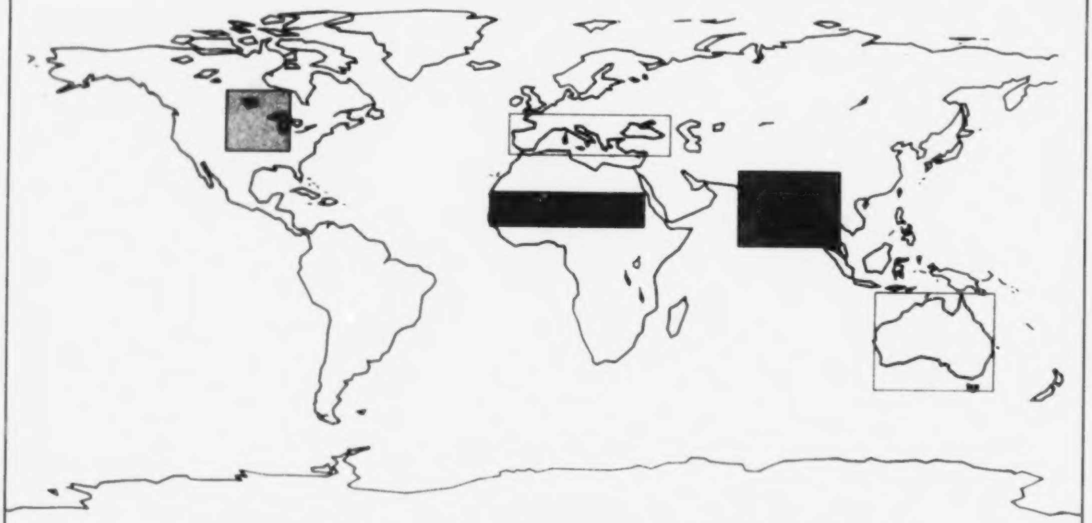
The warming varies from 1 to 2°C throughout the year. Precipitation changes little in winter and generally increases throughout the region by 5 to 15% in summer. Summer soil moisture increases by 5 to 10%.

[redacted]

The warming ranges from 1 to 3°C. Area mean precipitation increases and area mean soil moisture decreases marginally in summer. However, throughout the region, there are areas of both increase and decrease in both parameters throughout the region.

Southern Europe (35°–50°N 10°W–45°E)
The warming is about 2°C in winter and varies from 2 to 3°C in summer. There is some indication of increased precipitation in winter, but summer precipitation decreases by 5 to 15%, and summer soil moisture by 15 to 25%.

Australia (12°–45°S 110°–155°E)
The warming ranges from 1 to 2°C in summer and is about 2°C in winter. Summer precipitation increases by around 10%, but the models do not produce consistent estimates of the changes in soil moisture. The area averages hide large variations at the sub-continental level.



Map showing the locations and extents of the five areas selected by IPCC

100 years suggest that, with continued increases in greenhouse climate forcing, there could be significant changes in the ocean circulation, including a decrease in North Atlantic deep water formation.

Other factors which could influence future climate

Variations in the output of **solar energy** may also affect climate. On a decadal time-scale solar variability and changes in greenhouse gas concentration could give changes of similar magnitudes. However, the variation in solar intensity changes sign so that over longer time-scales the increases in greenhouse gases are likely to be more important. **Aerosols** as a result of volcanic eruptions can lead to a cooling at the surface which may oppose the greenhouse warming for a few years following an eruption. Again, over longer periods the greenhouse warming is likely to dominate.

Human activity is leading to an increase in aerosols in the lower atmosphere, mainly from sulphur emissions. These have two effects, both of which are difficult to quantify but which may be significant particularly at the regional level. The first is the direct effect of the aerosols on the radiation scattered and absorbed by the atmosphere. The second is an indirect effect whereby the aerosols affect the microphysics of clouds leading to an increased cloud reflectivity. Both these effects might lead to a significant regional cooling; a decrease in emissions of sulphur might be expected to increase global temperatures.

Because of long-period couplings between different components of the climate system, for example between ocean and atmosphere, the Earth's climate would still vary without being perturbed by any external influences. This **natural variability** could act to add to, or subtract from, any human-made warming; on a century time-scale this would be less than changes expected from greenhouse gas increases.

How much confidence do we have in our predictions?

Uncertainties in the above climate predictions arise from our imperfect knowledge of:

- future rates of human-made emissions
- how these will change the atmospheric concentrations of greenhouse gases
- the response of climate to these changed concentrations

Firstly, it is obvious that the extent to which climate will change depends on the rate at which greenhouse gases (and other gases which affect their concentrations) are emitted. This in turn will be determined by various complex economic and sociological factors. Scenarios of future emissions were generated within IPCC WG III and are described in the Annex.

Secondly, because we do not fully understand the sources and sinks of the greenhouse gases, there are uncertainties in our calculations of future concentrations arising from a given emissions scenario. We have used a number of models to calculate concentrations and chosen a best estimate for each gas. In the case of carbon dioxide, for example, the concentration increase between 1990 and 2070 due to the Business-as-Usual emissions scenario spanned almost a factor of two between the highest and lowest model result (corresponding to a range in radiative forcing change of about 50%).

Furthermore, because natural sources and sinks of greenhouse gases are sensitive to a change in climate, they may substantially modify future concentrations (see earlier section: "Greenhouse gas feedbacks" on page 10). It appears that, as climate warms, these feedbacks will lead to an overall increase, rather than decrease, in natural greenhouse gas abundances. For this reason, climate change is likely to be greater than the estimates we have given.

Thirdly, climate models are only as good as our understanding of the processes which they describe, and this is far from perfect. The ranges in the climate predictions given above reflect the uncertainties due to model imperfections; the largest of these is cloud feedback (those factors affecting the cloud amount and distribution and the interaction of clouds with solar and terrestrial radiation), which leads to a factor of two uncertainty in the size of the warming. Others arise from the transfer of energy between the atmosphere and ocean, the atmosphere and land surfaces, and between the upper and deep layers of the ocean. The treatment of sea-ice and convection in the models is also crude. Nevertheless, for reasons given in the box on page 20, we have substantial confidence that models can predict at least the broad-scale features of climate change.

Furthermore, we must recognize that our imperfect understanding of climate processes (and corresponding ability to model them) could make us vulnerable to surprises; just as the human-made ozone hole over Antarctica was entirely unpredicted. In particular, the ocean circulation, changes in which are thought to have led to periods of comparatively rapid climate change at the end of the last ice age, is not well observed, understood or modelled.

Will the climate of the future be very different?

When considering future climate change, it is clearly essential to look at the record of climate variation in the past. From it we can learn about the range of natural climate variability, to see how it compares with what we expect in the future, and also look for evidence of recent climate change due to man's activities.

Climate varies naturally on all time-scales from hundreds of millions of years down to the year to year. Prominent in the Earth's history have been the 100,000-year glacial-interglacial cycles when climate was mostly cooler than at present. Global surface temperatures have typically varied by 5–7°C through these cycles, with large changes in ice volume and sea level, and temperature changes as great as 10–15°C in some middle and high latitude regions of the northern hemisphere. Since the end of the last ice age, about 10,000 years ago, global surface temperatures have probably fluctuated by little more than 1°C. Some fluctuations have lasted several centuries, including the Little Ice Age which ended in the nineteenth century and which appears to have been global in extent.

The changes predicted to occur by about the middle of the next century due to increases in greenhouse gas concentrations from the Business-as-Usual emissions will make global mean temperatures higher than they have been for 150,000 years.

The **rate of change** of global temperatures predicted for Business-as-Usual emissions will be greater than those which have occurred naturally on Earth over the last 10,000 years, and the rise in sea level will be about three to six times faster than that seen over the last 100 years or so.

Confidence in predictions from climate models

What confidence can we have that climate change due to increasing greenhouse gases will look anything like the model predictions? Weather forecasts can be compared with the actual weather the next day and their skill assessed; we cannot do that with climate predictions. However, there are several indicators that give us some confidence in the predictions from climate models.

When the latest atmospheric models are run with the present atmospheric concentrations of greenhouse gases and observed boundary conditions, their simulation of present climate is generally realistic on large scales, capturing the major features such as the wet tropical convergence zones and mid-latitude depression belts, as well as the contrasts between summer and winter circulations. The models also simulate the observed variability; for example, the large day-to-day pressure variations in the middle-latitude depression belts and the maxima in interannual variability responsible for the very different character of one winter from another both being represented. However, on regional scales (2,000km or less), there are significant errors in all models.

Overall confidence is increased by atmospheric models generally satisfactory portrayal of aspects of variability of the atmosphere, for instance those associated with variations in sea surface temperature. There has been some success in simulating the general circulation of the ocean, including the patterns (though not always the intensities) of the principal currents, and the distributions of tracers added to the ocean.

Atmospheric models have been coupled with simple models of the ocean to predict the equilibrium response to greenhouse gases, under the assumption that the model errors are the same in a changed climate. The ability of such models to simulate important aspects of the climate of the last ice age generates confidence in their usefulness. Atmospheric models have also been coupled with multi-layer ocean models (to give coupled ocean–atmosphere GCMs) which predict the gradual response to increasing greenhouse gases. Although the models so far are of relatively coarse resolution, the large-scale structures of the ocean and the atmosphere can be simulated with some skill. However, the coupling of ocean and atmosphere models reveals a strong sensitivity to small-scale errors which leads to a drift away from the observed climate. As yet, these errors must be removed by adjustments to the exchange of heat between ocean and atmosphere. There are similarities between results from the coupled models using simple representations of the ocean and those using more sophisticated descriptions, and our understanding of such differences as do occur gives us some confidence in the results.

Has man already begun to change the global climate?

The instrumental record of surface temperature is fragmentary until the mid nineteenth century, after which it slowly improves. Because of different methods of measurement, historical records have to be harmonized with modern observations, introducing some uncertainty. Despite these problems we believe that a real warming of the globe of 0.3 to 0.6°C has taken place over the last century; any bias due to urbanization is likely to be less than 0.05°C.

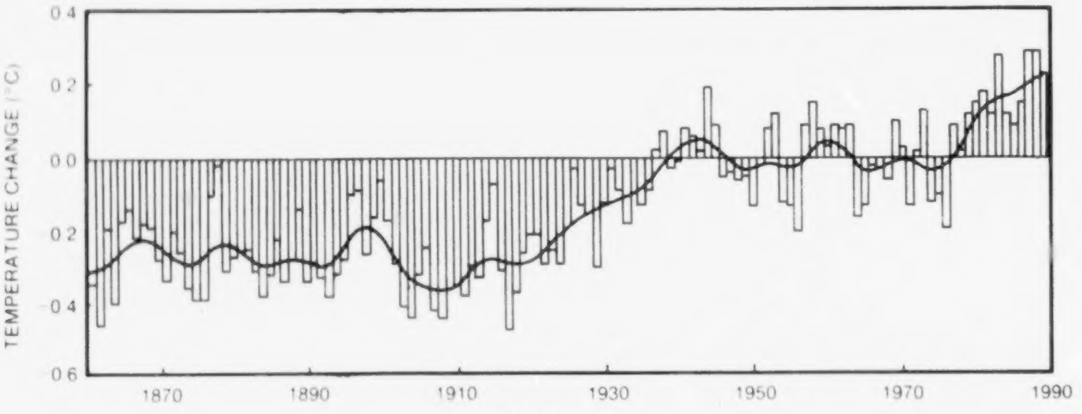
Moreover, since 1900 similar temperature increases are seen in three independent data sets: one collected over land and two over the oceans. The figure below shows current estimates of smoothed global mean surface temperature over land and ocean since 1860. Confidence in the record has been increased by their similarity to recent satellite measurements of mid-tropospheric temperatures.

Although the overall temperature rise has been broadly similar in both hemispheres, it has not been steady, and differences in their rates of warming have sometimes persisted for decades. Much of the warming since 1900 has been concentrated in two periods, the first between about 1910 and 1940 and the other since 1975; the five warmest years on record have all been in the 1980s. The northern hemisphere cooled between the 1940s and the early 1970s when southern hemisphere temperatures stayed nearly constant. The pattern of global warming since 1975 has been uneven with some regions, mainly in the northern hemisphere, continuing to cool until recently. This regional diversity indicates that future regional temperature changes are likely to differ considerably from a global average.

The conclusion that global temperature has been rising is strongly supported by the retreat of most **mountain glaciers** of the world since the end of the nineteenth century and the fact that global **sea level** has risen over the same period by an average of 1 to 2mm per year. Estimates of thermal expansion of the oceans, and of increased melting of mountain glaciers and the ice margin in west Greenland over the last century, show that the major part of the sea level rise appears to be related to the observed global warming. This apparent connection between observed sea level rise and global warming provides grounds for believing that future warming will lead to an acceleration in sea level rise.

The size of the warming over the last century is broadly consistent with the predictions of climate models, but is also of the same magnitude as natural climate variability. If the sole cause of the observed warming were the man-made greenhouse effect, then the implied climate sensitivity would be near the lower end of the range inferred from the models. The observed increase could be largely due to natural variability; alternatively this variability and other man-made factors could have offset a still larger man-made greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more, when the commitment to future climate change will then be considerably larger than it is today.

Global-mean temperature alone is an inadequate indicator of greenhouse-gas-induced climatic change. Identifying the causes of any global mean temperature change requires examination of other aspects of the changing climate, particularly its spatial and temporal characteristics — the man-made climate change "signal". Patterns of climate change from models such as the northern hemisphere



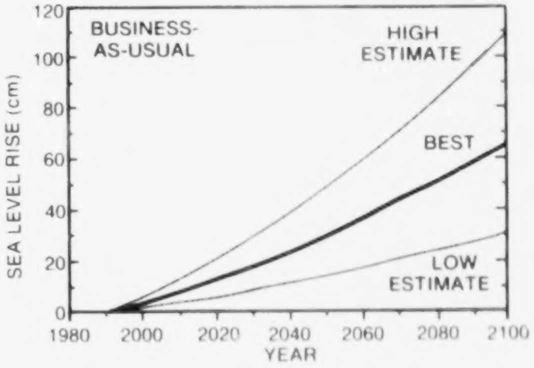
Annual deviation of global mean combined land-air and sea-surface temperatures for the period 1861-1989 (shown by bars), relative to the average for 1951-1980. The curve shows the results of a smoothing filter applied to the annual values.

warming faster than the southern hemisphere, and surface air warming faster over land than over oceans, are not apparent in observations to date. However, we do not yet know what the detailed "signal" looks like because we have limited confidence in our predictions of climate change patterns. Furthermore, any changes to date could be masked by natural variability and other (possibly man-made) factors, and we do not have a clear picture of these.

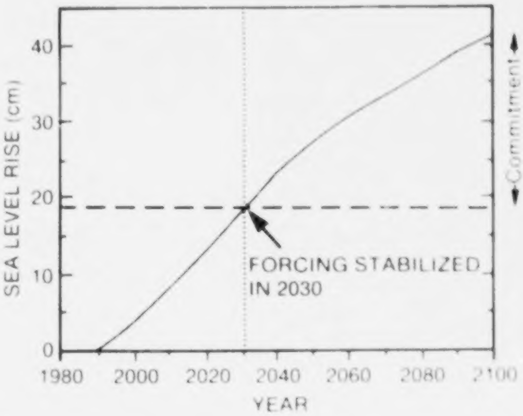
How much will sea level rise?

Simple models were used to calculate the rise in sea level to the year 2100; the results are illustrated here. The calculations necessarily ignore any long-term changes, unrelated to greenhouse forcing, that may be occurring but cannot be detected from the present data on land-ice and the ocean. The sea level rise expected from 1990–2100 under the IPCC Business-as-Usual emissions scenario is shown below; an average rate of global mean sea level rise of about 6 cm per decade over the next century (with an uncertainty range of 3–10cm per decade). The predicted rise is about 20cm in global mean sea level by 2030, and 65cm by the end of the next century. There will be significant regional variations.

The best estimate in each case is made up mainly of positive contributions from thermal expansion of the oceans and the melting of glaciers. Although, over the next 100 years, the effect of the Antarctic and Greenland ice sheets is expected to be small, they make a major contribution to the uncertainty in predictions.



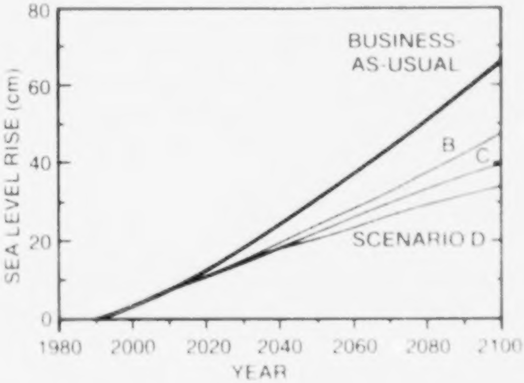
Sea level rise predicted to result from Business-as-Usual emissions, showing the best-estimate and range.



Commitment to sea level rise in the year 2030. The curve shows the sea level rise due to Business-as-Usual emissions to 2030, with the additional rise that would occur in the remainder of the century even if climate forcing was stabilized in 2030.

Even if greenhouse forcing increased no further, there would still be a commitment to a continuing sea level rise for many decades and even centuries, due to delays in climate, ocean and ice mass responses. As an illustration, if the increases in greenhouse gas concentrations were to suddenly stop in 2030, sea level would go on rising from 2030 to 2100, by as much again as from 1990–2030, as shown in the diagram above.

Predicted sea level rises due to the other three emissions scenarios are shown below, with the Business-as-Usual case for comparison; only best-estimate calculations are shown.



Model estimates of sea level rise from 1990 to 2100 due to all four emissions scenarios.

The West Antarctic Ice Sheet is of special concern. A large portion of it, containing an amount of ice equivalent to about 5m of global sea level, is grounded far below sea level. There have been suggestions that a sudden outflow of ice might result from global warming and raise sea level quickly and substantially. Recent studies have shown that individual ice streams are changing rapidly on a decade-to-century time-scale; however, this is not necessarily related to climate change. Within the next century, it is not likely that there will be a major outflow of ice from West Antarctica due directly to global warming.

Any rise in sea level is not expected to be uniform over the globe. Thermal expansion, changes in ocean circulation, and surface air pressure will vary from region to region as the world warms, but in an as yet unknown way. Such regional details await further development of more realistic coupled ocean atmosphere models. In addition, vertical land movements can be as large or even larger than changes in global mean sea level; these movements have to be taken into account when predicting local change in sea level relative to land.

The most severe effects of sea level rise are likely to result from extreme events (for example, storm surges) the incidence of which may be affected by climatic change.

What will be the effect of climate change on ecosystems?

Ecosystem processes such as photosynthesis and respiration are dependent on climatic factors and carbon dioxide concentration in the short term. In the longer term, climate and carbon dioxide are among the factors which control ecosystem structure, i.e. species composition, either directly by increasing mortality in poorly adapted species, or indirectly by mediating the competition between species. Ecosystems will respond to local changes in temperature (including its rate of change), precipitation, soil moisture and extreme events. Current models are unable to make reliable estimates of changes in these parameters on the required local scales.

Photosynthesis captures atmospheric carbon dioxide, water and solar energy and stores them in organic compounds which are then used for subsequent plant growth, the growth of animals or the growth of microbes in the soil. All of these organisms release carbon dioxide via respiration into the atmosphere. Most land plants have a system of photosynthesis which will respond positively to increased atmospheric carbon dioxide ("the carbon dioxide fertilization effect") but the response varies with species. The effect may decrease with time when restricted by other ecological limitations, for example, nutrient availability. It should be emphasized that the carbon content of the terrestrial biosphere will increase only if the forest ecosystems in a state of maturity will be able to store more carbon in a warmer climate and at higher concentrations of carbon dioxide. We do not yet know if this is the case.

The response to increased carbon dioxide results in greater efficiencies of water, light and nitrogen use. These increased efficiencies may be particularly important during drought and in arid/semi-arid and infertile areas.

Because species respond differently to climatic change, some will increase in abundance and/or range while others will decrease. Ecosystems will therefore change in structure and composition. Some species may be displaced to higher latitudes and altitudes, and may be more prone to local, and possibly even global, extinction; other species may thrive.

As stated above, ecosystem structure and species distribution are particularly sensitive to the rate of change of climate. We can deduce something about how quickly global temperature has changed in the past from palaeoclimatological records. As an example, at the end of the last glaciation, within about a century, temperature increased by up to 5°C in the North Atlantic region, mainly in western Europe. Although during the increase from the glacial to the current interglacial temperature simple tundra ecosystems responded positively, a similar rapid temperature increase applied to more developed ecosystems could result in their instability.

What should be done to reduce uncertainties, and how long will this take?

Although we can say that some climate change is unavoidable, much uncertainty exists in the prediction of global climate properties such as the temperature and rainfall. Even greater uncertainty exists in predictions of regional climate change, and the subsequent consequences for sea level and ecosystems. The key areas of scientific uncertainty are:

- **clouds**: primarily cloud formation, dissipation, and radiative properties, which influence the response of the atmosphere to greenhouse forcing;

Deforestation and Reforestation

Man has been deforesting the Earth for millennia. Until the early part of the century, this was mainly in temperate regions, more recently it has been concentrated in the tropics. Deforestation has several potential impacts on climate: through the carbon and nitrogen cycles (where it can lead to changes in atmospheric carbon dioxide concentrations), through the change in reflectivity of terrain when forests are cleared, through its effect on the hydrological cycle (precipitation, evaporation and runoff) and surface roughness and thus atmospheric circulation which can produce remote effects on climate.

It is estimated that each year about 2 Gt of carbon (GtC) is released to the atmosphere due to tropical deforestation. The rate of forest clearing is difficult to estimate; probably until the mid-20th century, temperate deforestation and the loss of organic matter from soils was a more important contributor to atmospheric carbon dioxide than was the burning of fossil fuels. Since then, fossil fuels have become dominant; one estimate is that around 1980, 1.6GtC was being released annually from the clearing of tropical forests, compared with about 5GtC from the burning of fossil fuels. If all the tropical forests were removed, the input is variously estimated at from 150 to 240GtC; this would increase atmospheric carbon dioxide by 35 to 60ppmv.

To analyse the effect of reforestation we assume that 10 million hectares of forests are planted each year for a period of 40 years, i.e. 4 million km^2 would then have been planted by 2030, at which time 1GtC would be absorbed annually until these forests reach maturity. This would happen in 40–100 years for most forests. The above scenario implies an accumulated uptake of about 20GtC by the year 2030 and up to 80GtC after 100 years. This accumulation of carbon in forests is equivalent to some 5–10% of the emission due to fossil fuel burning in the Business-as-Usual scenario.

Deforestation can also alter climate directly by increasing reflectivity and decreasing evapotranspiration. Experiments with climate models predict that replacing all the forests of the Amazon Basin by grassland would reduce the rainfall over the basin by about 20%, and increase mean temperature by several degrees.

- **oceans:** the exchange of energy between the ocean and the atmosphere, between the upper layers of the ocean and the deep ocean, and transport within the ocean, all of which control the rate of global climate change and the patterns of regional change;
- **greenhouse gases:** quantification of the uptake and release of the greenhouse gases, their chemical reactions in the atmosphere, and how these may be influenced by climate change;
- **polar ice sheets:** which affect predictions of sea level rise.

Studies of land surface hydrology, and of impact on ecosystems, are also important.

To reduce the current scientific uncertainties in each of these areas will require internationally co-ordinated research, the goal of which is to improve our capability to observe, model and understand the global climate system. Such a programme of research will reduce the scientific uncertainties and assist in the formulation of sound national and international response strategies.

Systematic long-term **observations** of the system are of vital importance for understanding the natural variability of the Earth's climate system, detecting whether man's activities are changing it, parametrizing key processes for models, and verifying model simulations. Increased accuracy and coverage in many observations are required. Associated with expanded observations is the need to develop appropriate comprehensive global information bases for the rapid and efficient dissemination and utilization of data. The main observational requirements are:

i) the maintenance and improvement of observations (such as those from satellites) provided by the World Weather Watch Programme of WMO.

ii) the maintenance and enhancement of a programme of monitoring, both from satellite-based and surface-based instruments, of key climate elements for which accurate observations on a continuous basis are required, such as the distribution of important atmospheric constituents, clouds, the Earth's radiation budget, precipitation, winds, sea surface temperatures and terrestrial ecosystem extent, type and productivity.

iii) the establishment of a global ocean observing system to measure changes in such variables as ocean surface topography, circulation, transport of heat and chemicals, and sea-ice extent and thickness.

iv) the development of major new systems to obtain data on the oceans, atmosphere and terrestrial ecosystems using both satellite-based instruments and instruments based on the surface, on automated instrumented vehicles in the ocean, on floating and deep sea buoys, and on aircraft and balloons, and

v) the use of palaeoclimatological and historical instrumental records to document natural variability and changes in the climate system, and subsequent environmental response.

The **modelling** of climate change requires the development of global models which couple together atmosphere, land, ocean and ice models and which incorporate more realistic formulations of the relevant processes and the interactions between the different components. Processes in the biosphere (both on land and in the ocean) also need to be included. Higher spatial resolution than is currently generally used is required if regional patterns are to be predicted. These models will require the largest computers which are planned to be available during the next decades.

Understanding of the climate system will be developed from analyses of observations and of the results from model simulations. In addition, detailed studies of particular processes will be required through targetted observational campaigns. Examples of such field campaigns include combined observational and small-scale modelling studies for different regions, of the formation, dissipation, radiative, dynamical and microphysical properties of clouds, and ground-based (ocean and land) and aircraft measurements of the fluxes of greenhouse gases from specific ecosystems. In particular, emphasis must be placed on field experiments that will assist in the development and improvement of sub-grid-scale parametrizations for models.

The required programme of research will require unprecedented international co-operation, with the World Climate Research Programme (WCRP) of the World Meteorological Organization and International Council of Scientific Unions (ICSU), and the International Geosphere-Biosphere Programme (IGBP) of ICSU both playing vital roles. These are large and complex endeavours that will require the involvement of all nations, particularly the developing countries. Implementation of existing and planned projects will require increased financial and human resources; the latter requirement has immediate implications at all levels of education, and the international community of scientists needs to be widened to include more members from developing countries.

The WCRP and IGBP have a number of ongoing or planned research programmes, that address each of the three key areas of scientific uncertainty. Examples include:

- **clouds:**
  International Satellite Cloud Climatology Project (ISCCP);
  Global Energy and Water Cycle Experiment (GEWEX).

- **oceans:**
  World Ocean Circulation Experiment (WOCE);
  Tropical Oceans and Global Atmosphere (TOGA).

- **trace gases:**
  Joint Global Ocean Flux Study (JGOFS);
  International Global Atmospheric Chemistry (IGAC);
  Past Global Changes (PAGES).

As research advances, increased understanding and improved observations will lead to progressively more reliable climate predictions. However, considering the complex nature of the problem and the scale of the scientific programmes to be undertaken we know that rapid results cannot be expected. Indeed further scientific advances may expose unforeseen problems and areas of ignorance.

Time-scales for narrowing the uncertainties will be dictated by progress over the next 10–15 years in two main areas:

- Use of the fastest possible computers, to take into account coupling of the atmosphere and the oceans in models, and to provide sufficient resolution for regional predictions.

- Development of improved representation of small-scale processes within climate models, as a result of the analysis of data from observational programmes to be conducted on a continuing basis well into the next century.

ANNEX

Emissions Scenarios From Working Group III Of The Intergovernmental Panel On Climate Change

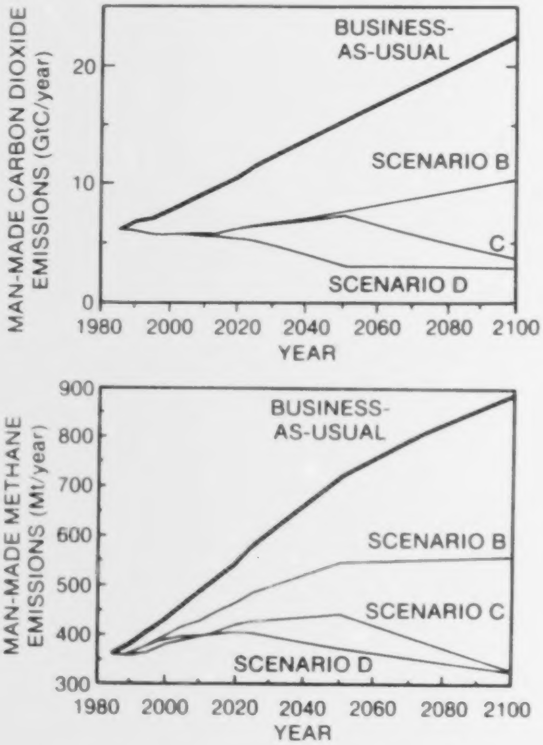
The Steering Group of the Response Strategies Working Group requested the USA and The Netherlands to develop emissions scenarios for evaluation by the IPCC Working Group I. The scenarios cover the emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), carbon monoxide (CO) and nitrogen oxides (NO_x) from the present up to the year 2100. Growth of the economy and population was taken common for all scenarios. Population was assumed to approach 10.5 billion in the second half of the next century. Economic growth was assumed to be 2–3% annually in the coming decade in the OECD countries and 3–5% in the eastern European and developing countries. The economic growth levels were assumed to decrease thereafter. In order to reach the required targets, levels of technological development and environmental controls were varied.

In the **Business-as-Usual scenario** (Scenario A) the energy supply is coal intensive and on the demand side only modest efficiency increases are achieved. Carbon monoxide controls are modest, deforestation continues until the tropical forests are depleted and agricultural emissions of methane and nitrous oxide are uncontrolled. For CFCs the Montreal Protocol is implemented albeit with only partial participation. Note that the aggregation of national projections by IPCC Working Group III gives higher emissions (10–20%) of carbon dioxide and methane by 2025.

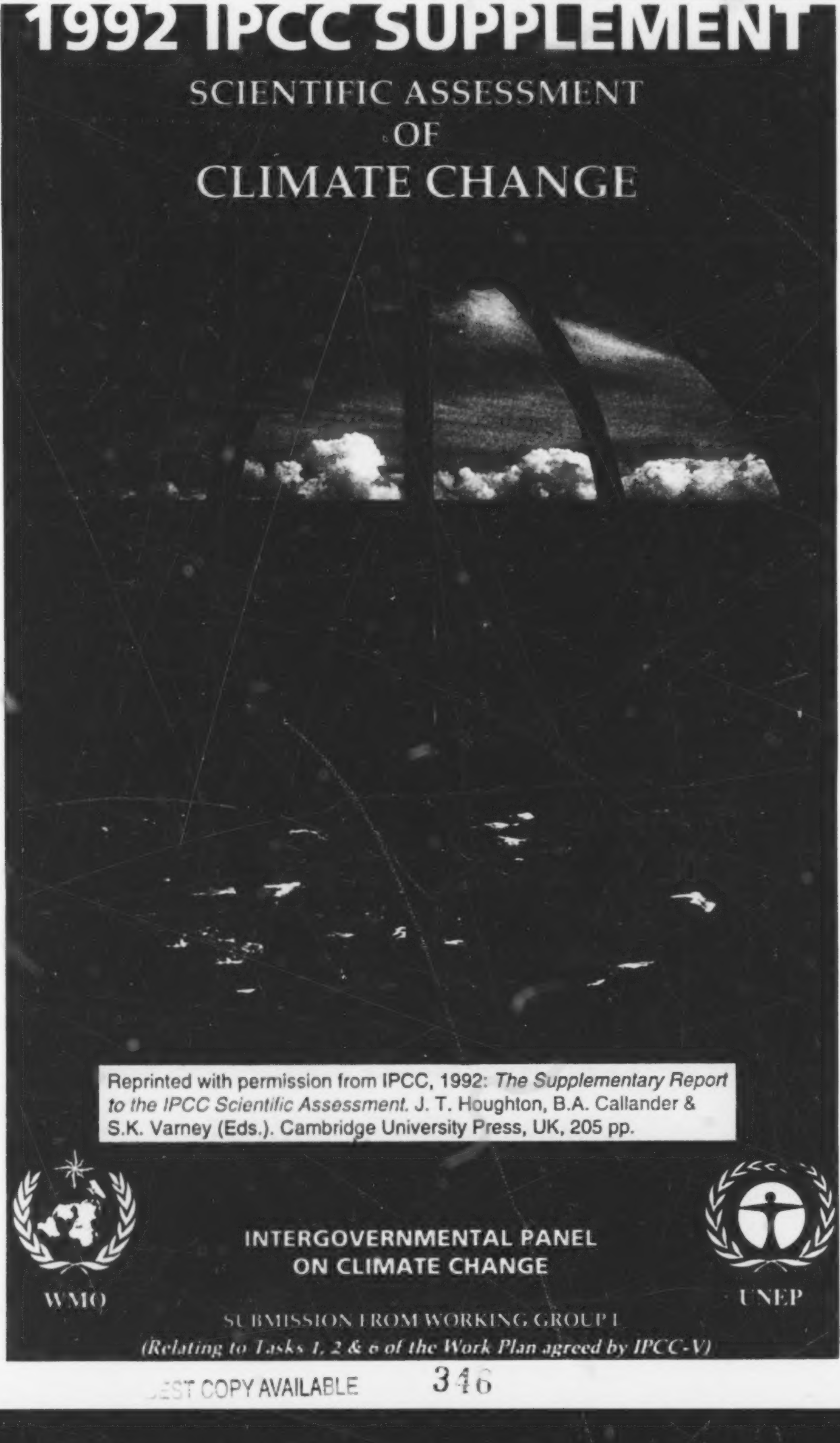
In **Scenario B** the energy supply mix shifts towards lower carbon fuels, notably natural gas. Large efficiency increases are achieved. Carbon monoxide controls are stringent, deforestation is reversed and the Montreal Protocol implemented with full participation.

In **Scenario C** a shift towards renewables and nuclear energy takes place in the second half of next century. CFCs are now phased out and agricultural emissions limited.

For **Scenario D** a shift to renewables and nuclear in the first half of the next century reduces the emissions of carbon dioxide, initially more or less stabilizing emissions in the industrialized countries. The scenario shows that stringent controls in industrialized countries combined with moderated growth of emissions in developing countries could stabilize atmospheric concentrations. Carbon dioxide emissions are reduced to 50% of 1985 levels by the middle of the next century.



Man-made emissions of carbon dioxide and methane (as examples) to the year 2100, in the four scenarios developed by IPCC Working Group III.



1992 IPCC SUPPLEMENT

SCIENTIFIC ASSESSMENT
OF
CLIMATE CHANGE

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WMO

INTERGOVERNMENTAL PANEL
ON CLIMATE CHANGE

UNEP

SUBMISSION FROM WORKING GROUP I
(Relating to Tasks 1, 2 & 6 of the Work Plan agreed by IPCC-V)

1992 IPCC SUPPLEMENT: SCIENTIFIC ASSESSMENT

PREFACE

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by our two organizations in 1988, under the Chairmanship of Professor Bert Bolin. The Panel formed three Working Groups:

- (a) to assess the available scientific information on climate change,
- (b) to assess the environmental and socio-economic impacts of climate change, and
- (c) to formulate response strategies.

The Panel also established a Special Committee on the Participation of Developing Countries to promote the participation of those countries in its activities.

The IPCC First Assessment Report was completed in August 1990 and consists of the IPCC Scientific Assessment, the IPCC Impacts Assessment, the IPCC Response Strategies, the Policymakers' Summary of the IPCC Special Committee and the IPCC Overview. The Report has now become a standard work of reference, widely used by policymakers, scientists and other experts, and encompasses a remarkable coordinated effort by hundreds of specialists from all over the world.

Anticipating the need in 1992 for the latest information on climate change, in the context of the ongoing negotiations on the Framework Convention on Climate Change and the United Nations Conference on Environment and Development (Rio de Janeiro, June 1992), the Panel in 1991 requested its three Working Groups to produce updates to their 1990 Reports, addressing the key conclusions of the 1990 Assessment in the light of new data and analyses. The current publication is the result of the effort of Working Group I to produce an update of the IPCC Scientific Assessment.

As in 1990, success in producing this Report has depended upon the enthusiasm and cooperation of scientists worldwide. We admire, applaud, and are grateful for their commitment to the IPCC process. We also take this opportunity to express our gratitude to Professor Bolin for his very able leadership of the IPCC, and once again congratulate Sir John Houghton, Chairman of Working Group I, and his secretariat for another job well done.

G.O.P. Obasi
Secretary-General
World Meteorological Organization

M.K. Tolba
Executive Director
United Nations Environment Programme

1992 IPCC SUPPLEMENT: SCIENTIFIC ASSESSMENT

1. Current Task

The fifth session of the Intergovernmental Panel on Climate Change (IPCC) (Geneva, March 1991) adopted six tasks for the ongoing work of its three working groups. While successful completion of these tasks required cooperation between all three groups, particular responsibility fell to the Scientific Assessment working group (WGI) for Tasks 1, 2 and 6:

Task 1: Assessment of net greenhouse gas emissions.
Sub-section 1: Sources and sinks of greenhouse gases.
Sub-section 2: Global Warming Potentials.

Task 2: Predictions of the regional distributions of climate change and associated impact studies, including model validation studies.

Task 6: Emissions scenarios.

The tasks were divided into long- and short-term components. The purpose of the short-term workplan, whose results are reported in the present document, was to provide an update to the 1990 IPCC Scientific Assessment, addressing some of the key issues of that report. This update is by definition less comprehensive than the 1990 report - for example sea level rise apart from the effect of thermal expansion is not included. It is against the background of that document that the findings of this update should be read.

This assessment, in order to incorporate as much recent material as possible, necessarily includes discussion of new results which have not yet been through, or are currently undergoing, the normal process of peer review. Where such is the case the provisional nature of the results has been taken into account.

A brief progress report on the preparation of guidelines for the compilation of national inventories of greenhouse gas emissions, part of WGI's long-term work under Task 1, appears as an Annex to this Supplement.

2. Our Major Conclusions

Findings of scientific research since 1990 do not affect our fundamental understanding of the science of the greenhouse effect and either confirm or do not justify alteration of the major conclusions of the first IPCC Scientific Assessment, in particular the following:

- *emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide;*

- *the evidence from the modelling studies, from observations and the sensitivity analyses indicate that the sensitivity of global mean surface temperature to doubling CO_2 is unlikely to lie outside the range 1.5° to 4.5°C;*

- *there are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change;*

- *global mean surface air temperature has increased by 0.3° to 0.6°C over the last 100 years;*

- *the size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming;*

- *the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.*

There are also a number of significant new findings and conclusions which we summarize as follows:

Gases and Aerosols

- Depletion of ozone in the lower stratosphere in the middle and high latitudes results in a decrease in radiative forcing which is believed to be comparable in magnitude to the radiative forcing contribution of chlorofluorocarbons (CFCs) (globally-averaged) over the last decade or so.

- The cooling effect of aerosols (*) resulting from sulphur emissions may have offset a significant part of the greenhouse warming in the Northern Hemisphere (NH) during the past several decades. Although this phenomenon was recognized in the 1990 report, some progress has been made in quantifying its effect.

(*) *The scientific definition of 'aerosol' is an airborne particle or collection of particles, but the word has become associated, erroneously, with the propellant used in 'aerosol sprays'. Throughout this report the term 'aerosol' means airborne particle or particles.*

- The Global Warming Potential (GWP) remains a useful concept but its practical utility for many gases depends on adequate quantification of the indirect effects as well as of the direct. We now recognize that there is increased uncertainty in the calculation of GWPs, particularly in the indirect components and, whilst indirect GWPs are likely to be significant for some gases, the numerical estimates in this Supplementary Report are limited to direct GWPs only.

- Whilst the rates of increase in the atmospheric concentrations of many greenhouse gases have continued to grow or remain steady, those of methane and some halogen compounds have slowed.

- Some data indicate that global emissions of methane from rice paddies may amount to less than previously estimated.

Scenarios

- Steps have been taken towards a more comprehensive analysis of the dependence of future greenhouse gas emissions on socio-economic assumptions and projections. A set of updated scenarios has been developed for use in modelling studies which describes a wide range of possible future emissions in the absence of coordinated policy response to climate change.

Modelling

- Climate models have continued to improve in respect of both their physical realism and their ability to simulate present climate on large scales, and new techniques are being developed for the simulation of regional climate.

- Transient (time-dependent) simulations with coupled ocean-atmosphere models (CGCMs), in which neither aerosols nor ozone changes have been included, suggest a rate of global warming that is consistent, within the range of uncertainties, with the 0.3°C per decade warming rate quoted by IPCC (1990) for Scenario A of greenhouse gas emissions.

- The large-scale geographical patterns of warming produced by the transient model runs with CGCMs are generally similar to the patterns produced by the earlier equilibrium models except that the transient simulations show reduced warming over the northern North Atlantic and the southern oceans near Antarctica.

- CGCMs are capable of reproducing some features of atmospheric variability on intra-decadal time-scales.

- Our understanding of some climate feedbacks and their incorporation in the models has improved. In particular, there has been some clarification of the role of upper tropospheric water vapour. The role of other processes, in particular cloud effects, remains unresolved.

Climate Observations

- The anomalously high global mean surface temperatures of the late 1980s have continued into 1990 and 1991, which are the warmest years in the record.

- Average warming over parts of the Northern Hemisphere mid-latitude continents has been found to be largely characterized by increases in minimum (night-time) rather than maximum (daytime) temperatures.

- Radiosonde data indicate that the lower troposphere has warmed over recent decades. Since meaningful trends cannot be assessed over periods as short as a decade, the widely reported disagreements between decadal trends of air temperature from satellite and surface data cannot be confirmed because the trends are statistically indistinguishable.

- The volcanic eruption of Mount Pinatubo in 1991 is expected to lead to transitory stratospheric warming. With less certainty, because of other natural influences, surface and tropospheric cooling may occur during the next few years.

- Average warming over the Northern Hemisphere during the last four decades has not been uniform, with marked seasonal and geographic variations; this warming has been especially slow, or absent, over the extratropical north-west Atlantic.

- The consistency between observations of global temperature changes over the past century and model simulations of the warming due to greenhouse gases over the same period is improved if allowance is made for the increasing evidence of a cooling effect due to sulphate aerosols and to stratospheric ozone depletion.

The above conclusions have implications for future projections of global warming and somewhat modify the estimated rate of warming of 0.3°C per decade for the greenhouse gas emissions Scenario A of the IPCC 1990 Report. If sulphur emissions continue to increase, this warming rate is likely to be reduced, significantly in the Northern Hemisphere, by an amount dependent on the future magnitude and regional distribution of the emissions. Because sulphate aerosols are very short-lived in the atmosphere their effect on global warming rapidly adjusts to increases or decreases in emissions. It should also be noted that while partially offsetting the greenhouse warming, the sulphur emissions are also responsible for acid rain and other environmental effects. There is a further small net reduction likely in the rate of global warming during the next few decades due to decreases in stratospheric ozone, partially offset by increases in tropospheric ozone.

Research carried out since the 1990 IPCC Assessment has served to improve our appreciation of key uncertainties. There is a continuing need for increased monitoring and research into climate processes and modelling. This must involve, in particular, strengthened international collaboration through the World Climate Research Programme (WCRP), the International Geosphere Biosphere Programme (IGBP) and the Global Climate Observing System (GCOS).

How does the climate system work, and what information do we need to estimate future changes?

• *How does the climate system work?*

The Earth absorbs radiation from the Sun, mainly at the surface. This energy is then redistributed by the atmosphere and ocean and re-radiated to space at longer ('thermal', 'terrestrial' or 'infrared') wavelengths. Some of the thermal radiation is absorbed by radiatively-active ('greenhouse') gases in the atmosphere, principally water vapour, but also carbon dioxide, methane, the CFCs, ozone and other greenhouse gases. The absorbed energy is re-radiated in all directions, downwards as well as upwards such that the radiation that is eventually lost to space is from higher, colder levels in the atmosphere (see diagram below). The result is that the surface loses less heat to space than it would do in the absence of the greenhouse gases and consequently stays warmer than it would otherwise be. This phenomenon, which acts rather like a 'blanket' around the Earth, is known as the greenhouse effect.

• *What factors can change climate?*

Any factor which alters the radiation received from the Sun or lost to space, or which alters the redistribution of energy within the atmosphere, and between the atmosphere, land and ocean, will affect climate.

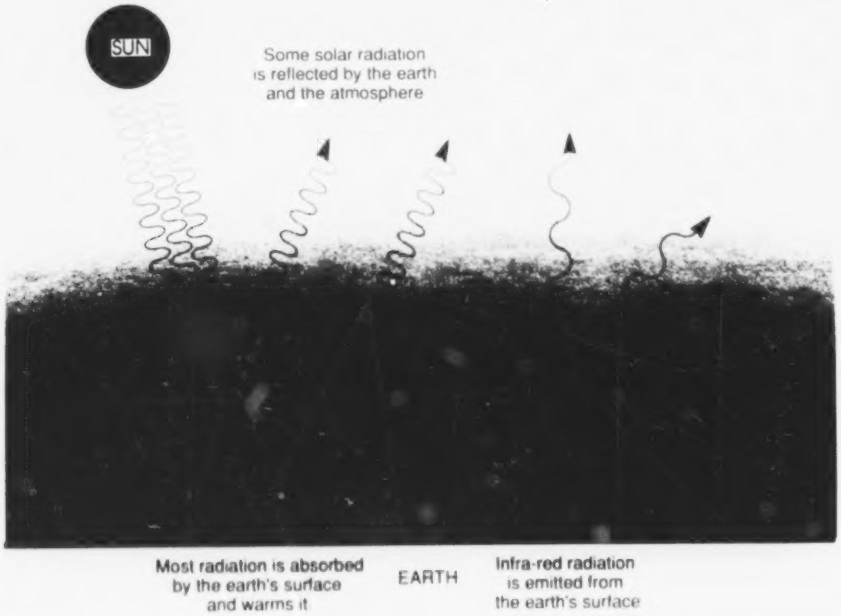
The Sun's output of energy is known to change by small amounts over an 11-year cycle, and variations over longer periods may occur. On time-scales of tens to thousands of years, slow variations in the Earth's orbit have led to changes in the seasonal and latitudinal distribution of solar radiation; these changes have played an important part in controlling the variations of past climate.
Increases in the concentration of the greenhouse gases will reduce the efficiency with which the Earth cools to space and will tend to warm the lower atmosphere and surface. The amount of warming depends on the size of the increase in concentration of each greenhouse gas, the radiative properties

of the gases involved, and the concentration of other greenhouse gases already present in the atmosphere. It also can depend on local effects such as the variation with height of the concentration of the greenhouse gas, a consideration that may be particularly germane to water vapour which is not uniformly mixed throughout the atmosphere. The effect is not a simple one and the balance which is struck between these factors depends on many aspects of the climate system.

Aerosols (small particles) from volcanoes, and sulphates derived from emissions from industry and other sources can absorb and reflect radiation. Moreover, changes in aerosol concentrations can alter cloud reflectivity through their effect on cloud properties. In most cases aerosols tend to cool climate. In general, they have a much shorter lifetime than greenhouse gases so their concentrations respond much more quickly to changes in emissions.

Any changes in the radiative balance of the Earth, including those due to an increase in greenhouse gases or in aerosols, will tend to alter atmospheric and oceanic temperatures and the associated circulation and weather patterns. However, climate varies naturally on all time-scales due to both external and internal factors. To distinguish man-made climate variations from those natural changes, it is necessary to identify the man-made 'signal' against the background 'noise' of natural climate variability.

A necessary starting point for the prediction of changes in climate due to increases in greenhouse gases and aerosols is an estimate of their future concentrations. This requires a knowledge of both the strengths of their sources (natural and man-made) and also the mechanisms of their eventual removal from the atmosphere (their sinks). The projections of future concentrations can then be used in climate models to estimate the climatic response. We also need to determine whether or not the predicted changes will be noticeable above the natural variations in climate. Finally, observations are essential in order to monitor climate, to study climatic processes and to help in the development and validation of models.


SUN
Some solar radiation is reflected by the earth and the atmosphere
Most radiation is absorbed by the earth's surface and warms it
EARTH
Infra-red radiation is emitted from the earth's surface

A simplified diagram illustrating the greenhouse effect.

3. How has our Understanding of the Sources and Sinks of Greenhouse Gases and Aerosols Changed?

During the last eighteen months there have been a number of important advances in our understanding of greenhouse gases and aerosols. These advances include an improved quantitative understanding of the atmospheric distributions, trends, sources and sinks of greenhouse gases, their precursors and aerosols, and an improved understanding of the processes controlling their global budgets.

Atmospheric Concentrations and Trends of Long-lived Greenhouse Gases: The atmospheric concentrations of the major long-lived greenhouse gases [carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and carbon tetrachloride (CCl_4)] continue to increase because of human activities. While the growth rates of most of these gases have been steady or increasing over the past decade, that of CH_4 and some of the halocarbons has been decreasing. The rate for CH_4 has declined from about 20 ppbv/yr in the late 1970s to possibly as low as 10 ppbv/yr in 1989. While a number of hypotheses have been forwarded to explain these observations, none is completely satisfactory.

Atmospheric Concentrations and Trends of Other Gases that Influence the Radiative Budget: Ozone (O_3) is an effective greenhouse gas both in the stratosphere and in the troposphere. Significant decreases have been observed during the last one to two decades in total column O_3 at all latitudes - except the tropics - in spring, summer and winter. The downward trends were larger during the 1980s than in the 1970s. These decreases have occurred predominantly in the lower stratosphere (below 25km), where the rate of decrease has been up to 10% per decade depending on altitude. In addition, there is evidence to indicate that O_3 levels in the troposphere up to 10 km altitude above the few existing ozonesonde stations at northern middle latitudes have increased by about 10% per decade over the past two decades. Also, the abundance of carbon monoxide (CO) appears to be increasing in the NH at about 1% per year. However, there is little new information on the global trends of other tropospheric O_3 precursors (non-methane hydrocarbons (NMHC) and oxides of nitrogen (NO_x)).

Sources and Sinks of Carbon Dioxide: The two primary sources of the observed increase in atmospheric CO_2 are combustion of fossil fuels and land-use changes; cement production is a further important source.

The emission of CO_2 from the combustion of fossil fuels grew between 1987 and 1989. Preliminary data for 1990 indicate similar emissions to 1989. The best estimate for global fossil fuel emissions in 1989 and 1990 is 6.0±0.5 GtC (†), compared to 5.7±0.5 GtC in 1987 (IPCC, 1990). The estimated total release of carbon in the form of CO_2 from oil well fires in Kuwait during 1991 was 0.065 GtC, about one percent of total annual anthropogenic emissions.

The direct net flux of CO_2 from land use changes (primarily deforestation), integrated over time, depends upon the area of land deforested, the rate of reforestation and afforestation, the carbon density of the original and replacement forests, and the fate of above-ground and soil carbon. These and other factors are needed to estimate annual net emissions but significant uncertainties exist in our quantitative knowledge of them. Since IPCC (1990) some progress has been made in reducing the uncertainties associated with the rate of deforestation, at least in Brazil. A comprehensive, multi-year, high spatial resolution satellite data set has been used to to estimate that the average rate of deforestation in the Brazilian Amazonian forest between 1978 and 1989 was 2.1 million hectares (Mha) per year. The rate increased between 1978 and the mid-1980s, and has decreased to 1.4 Mha/yr in 1990. The Food and Agriculture Organization (FAO), using information supplied by individual countries, recently estimated that the rate of global tropical deforestation in closed and open canopy forests for the period 1981-1990 was about 17 Mha/yr, approximately 50% higher than in the period 1976-1980.

Despite the new information regarding rates of deforestation, the uncertainties in estimating CO_2 emissions are so large that there is no strong reason to revise the IPCC 1990 estimate of annual average net flux to the atmosphere of 1.6±1.0 GtC from land-use change during the decade of the 1980s.

Since IPCC (1990) particular attention has focussed on understanding the processes controlling the release and uptake of CO_2 from both the terrestrial biosphere and the oceans, and on the quantification of the fluxes. Based on models and the atmospheric distribution of CO_2, it appears that there is a small net

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(†) - 1 GtC (gigatonne of carbon) equals one billion [one thousand million (10^9)] tonnes of carbon

addition of carbon to the atmosphere from the equatorial region, a combination of outgassing of CO_2 from warm tropical waters and a terrestrial biospheric component that is the residual between large sources (including deforestation) and sinks. There appears to be a strong Northern Hemisphere sink, containing both oceanic and terrestrial biospheric components, and a weak Southern Hemisphere (SH) sink. The previous IPCC global estimate for an ocean sink of 2.0±0.8 GtC per year is still a reasonable one. The terrestrial biospheric processes which are suggested as contributing to the sinks are sequestration due to forest regeneration, and fertilization arising from the effects of both CO_2 and nitrogen (N), but none of these can be adequately quantified. This implies that the imbalance (of order 1-2 GtC/yr) between sources and sinks, i.e., "the missing sink", has not yet been resolved. This fact has significant consequences for estimates of future atmospheric CO_2 concentrations (see Section 5) and the analysis of the concept of the Greenhouse Warming Potential (see Section 6).

Sources of Methane: A total (anthropogenic plus natural) annual emission of CH_4 of about 500Tg can be deduced from the magnitude of its sinks combined with its rate of accumulation in the atmosphere. While the sum of the individual sources is consistent with a total of 500Tg CH_4, there are still many uncertainties in accurately quantifying the magnitude of emissions from individual sources. Significant new information includes a revised rate of removal of CH_4 by atmospheric hydroxyl (OH) radicals (because of a lower rate constant), a new evaluation of some of the sources (e.g., from rice fields) and the addition of new sources (e.g., animal and domestic waste). Recent CH_4 isotopic studies suggest that approximately 100Tg CH_4 (20% of the total CH_4 source) is of fossil origin, largely from the coal, oil, and natural gas industries. Recent studies of CH_4 emissions from rice agriculture, in particular Japan, India, Australia, Thailand and China, show that the emissions depend on growing conditions, particularly soil characteristics, and vary significantly. While the overall uncertainty in the magnitude of global emissions from rice agriculture remains large, a detailed analysis now suggests significantly lower annual emissions than reported in IPCC 1990. The latest estimate of the atmospheric lifetime of CH_4 is about 11 years.

Sources of Nitrous Oxide: Adipic acid (nylon) production, nitric acid production and automobiles with three-way catalysts have been identified as possibly significant anthropogenic global sources of nitrous oxide. However, the sum of all known anthropogenic and natural sources is still barely sufficient to balance the calculated atmospheric sink or to explain the observed increase in the atmospheric abundance of N_2O.

Sources of Halogenated Species: The worldwide consumption of CFCs 11, 12, and 113 is now 40% below 1986 levels, substantially below the amounts permitted under the Montreal Protocol. Further reductions are mandated by the 1990 London Amendments to the Montreal Protocol. As CFCs are phased out, HCFCs and HFCs will substitute, but at lower emission rates.

Stratospheric Ozone Depletion: Even if the control measures of the 1990 London amendments to the Montreal Protocol were to be implemented by all nations, the abundance of stratospheric chlorine and bromine will increase over the next several years. The Antarctic ozone hole, caused by industrial halocarbons, will therefore recur each spring. In addition, as the weight of evidence suggests that these gases are also responsible for the observed reductions in middle- and high-latitude stratospheric O_3, the depletion at these latitudes is predicted to continue unabated through the 1990s.

Sources of Precursors of Tropospheric Ozone: Little new information is available regarding the tropospheric ozone precursors (CO, NMHC, and NO_x), all of which have significant natural and anthropogenic sources. Their detailed budgets therefore remain uncertain.

Source of Aerosols: Industrial activity, biomass burning, volcanic eruptions, and sub-sonic aircraft contribute substantially to the formation of tropospheric and stratospheric aerosols. Industrial activities are concentrated in the Northern Hemisphere where their impact on tropospheric sulphate aerosols is greatest. Sulphur emissions, which are due in large part to combustion effluents, have a similar emissions history to that of anthropogenic CO_2. Estimates of emissions of natural sulphur compounds have been reduced from previous figures, thereby placing more emphasis on the anthropogenic contribution.

4. Scenarios of Future Emissions

Scenarios of net greenhouse gas and aerosol precursor emissions for the next 100 years or more are necessary to support study of potential anthropogenic impacts on the climate system. The scenarios provide inputs to climate models and assist in the examination of the relative importance of relevant trace gases and aerosol precursors in changing atmospheric composition and climate. Scenarios can also help in improving the understanding of key relationships among factors that drive future emissions.

Scenario outputs are not predictions of the future, and should not be used as such; they illustrate the effect of a wide range of economic, demographic and policy assumptions. They are inherently controversial because they reflect different views of the future. The results of scenarios can vary considerably from actual outcomes even over short time horizons. Confidence in scenario outputs decreases as the time horizon increases, because the basis for the underlying assumptions becomes increasingly speculative. Considerable uncertainties surround the evolution of the types and levels of human activities (including economic growth and structure), technological advances, and human responses to possible environmental, economic and institutional constraints. Consequently, emission scenarios must be constructed carefully and used with great caution.

Since completion of the 1990 IPCC Scenario A (SA90) events and new information have emerged which relate to that scenario's underlying assumptions. These developments include: the London Amendments to the Montreal Protocol; revision of population forecasts by the World Bank and United Nations; publication of the IPCC Energy and Industry Sub-group scenario of greenhouse gas emissions to 2025; political events and economic changes in the former USSR, Eastern Europe and the Middle East; re-estimation of sources and sinks of greenhouse gases (reviewed in this Assessment); revision of preliminary FAO data on tropical deforestation; and new scientific studies on forest biomass. There has also been recognition of considerable uncertainty regarding other important factors that drive future emissions.

These factors have led to an update of SA90. Six alternative IPCC Scenarios (IS92 a-f) now embody a wide array of assumptions, summarized in Table 1, affecting how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted. This constitutes a significant improvement over the previous methodology. However, the probability of any of the resulting emission paths has not been analyzed. IPCC WGI does not prefer any individual scenario. Other combinations of assumptions could illustrate a broader variety of emission trajectories. The different worlds which the new scenarios imply, in terms of economic, social and environmental conditions, vary widely. The current exercise provides an interim view and lays a basis for a more complete study of future emissions of greenhouse gas and aerosol precursors.

Scenario Results: The range of possible greenhouse gas futures is very wide, as the Figure overleaf illustrates (showing only CO_2). All six scenarios can be compared to SA90. IS92a is slightly lower than SA90 due to modest and largely offsetting changes in the underlying assumptions. (For example, compared to SA90, higher population forecasts increase the emission estimates, while phaseout of halocarbons and more optimistic renewable energy costs reduce them.) The highest greenhouse gas levels result from the new scenario IS92e which combines, among other assumptions, moderate population growth, high economic growth, high fossil fuel availability and eventual hypothetical phaseout of nuclear power. The lowest greenhouse gas levels result from IS92c which assumes that population grows, then declines by the middle of the next century, that economic growth is low and that there are severe constraints on fossil fuel supplies. The results of all six scenarios appear in Table 2. Overall, the scenarios indicate that greenhouse gas emissions could rise substantially over the coming century in the absence of new measures explicitly intended to reduce their emission. However, IS92c has a CO_2 emission path which eventually falls below its starting 1990 level. IS92b, a modification of IS92a, suggests that current commitments by many OECD Member countries to stabilize or reduce CO_2 might have a small impact on greenhouse gas emissions over the next few decades, but would not offset substantial growth in possible emissions in the long run. IS92b does not take into account the possibility that such commitments could accelerate development and diffusion of low greenhouse gas technologies, nor possible resulting shifts in industrial mix.

Table 1: Summary of Assumptions in the Six IPCC 1992 Alternative Scenarios. †

Scenario	Population	Economic	Growth	Energy Supplies ††	Other	CFCs
IS92a	World Bank 1991 11.3 B by 2100	1990-2025: 1990-2100:	2.9% 2.3%	12,000 EJ Conventional Oil 13,000 EJ Natural Gas Solar costs fall to $0.075/kWh 191 EJ of biofuels available at $70/barrel	Legally enacted and internationally agreed controls on SOx, NOx and NMVOC emmissions.	Partial compliance with Montreal Protocol. Technological transfer results in gradual phase out of CFCs also in non-signatory countries by 2075.
IS92b	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	2.9% 2.3%	Same as "a"	Same as "a" plus commitments by many OECD countries to stabilize or reduce CO_2 emissions.	Global compliance with scheduled phase out of Montreal Protocol.
IS92c	UN Medium Low Case 6.4 B by 2100	1990-2025 1990-2100	2.0% 1.2%	8,000 EJ Conventional Oil 7,300 EJ Natural Gas Nuclear costs decline by 0.4% annually.	Same as "a"	Same as "a"
IS92d	UN Medium Low Case 6.4 B by 2100	1990-2025 1990-2100	2.7% 2.0%	Oil and gas as "c" Solar costs fall to $0.065/kWh 272 EJ of biofuels available at $50/barrel	Emission controls extended worldwide for CO, NOx, NMVOC and SOx. Halt deforestation. Capture and use of emissions from coal mining and gas production and use.	CFC production phase out by 1997 for industrialized countries. Phase out for HCFCs.
IS92e	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	3.5% 3.0%	18,400 EJ convential oil Gas same as "a" Phase out nuclear by 2075	Emission controls (30% pollution surcharge on fossil energy).	Same as "d"
IS92f	UN Medium High Case 17.6 B by 2100	Same as "a"		Oil and gas same as "e" Solar costs fall to $0.083/kWh Nuclear costs increase to $0.09/kWh	Same as "a"	Same as "a"

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† The assumptions for the 1990 Scenario A are described in IPCC (1990) Annex A, pp.331-339.

†† All scenarios assume coal resources up to 197,000 EJ. Up to 15% of this resource is assumed to be available at $1.30/gigajoule at the mine.

††† Tropical deforestation rates (for closed and open forests) begin from an average rate of 17.0 million hectares/year (FAO, 1991) for 1981-1990, then increase with population until constrained by availability of land not legally protected. IS91d assumes an eventual halt of deforestation for reasons other than climate. Above ground carbon density per hectare varies with forest type from 16 to 117 tons C/hectare, with soil C ranging from 68 to 100 T C/ha. However, only a portion of carbon is released over time with land conversion, depending on type of land conversion.

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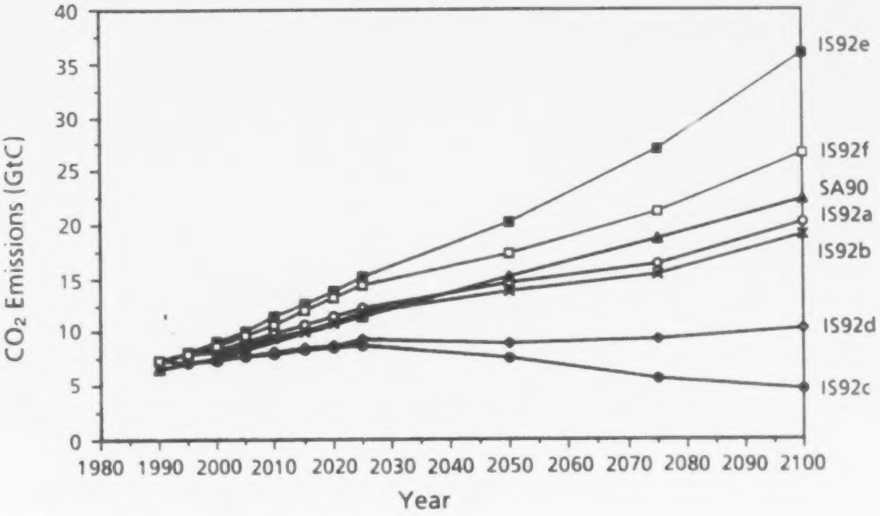
Carbon Dioxide: The new emissions scenarios for CO_2 from the energy sector span a broad range of futures (see Figure below).

CO_2 Emissions from Energy, Cement Production and Deforestation



Population and economic growth, structural changes in economies, energy prices, technological advance, fossil fuel supplies, nuclear and renewable energy availability are among the factors which could exert major influence on future levels of CO_2 emissions. Developments such as those in the republics of the former Soviet Union and in Eastern Europe, now incorporated into all the scenarios, have important implications for future fossil fuel carbon emissions, by affecting the levels of economic activities and the efficiency of energy production and use. Biotic carbon emissions in the early decades of the scenarios are higher than SA90, reflecting higher preliminary FAO estimates of current rates of deforestation in many - though not all - parts of the world, and higher estimates of forest biomass.

Halocarbons: The revised scenarios for CFCs and other substances which deplete stratospheric ozone are much lower than in SA90. This is consistent with wide participation in the controls under the 1990 London Amendments to the Montreal Protocol. However, the future production and composition of CFC substitutes (HCFCs and HFCs) could significantly affect the levels of radiative forcing from these compounds.

Methane, Nitrous Oxide, Ozone Precursors and Sulphur Gases: The distribution of CH_4 and N_2O emissions from the different sources has changed from the SA90 case. Methane from rice paddies is lower, and emissions from animal waste and domestic sewage have been added. N_2O emission factors for stationary sources and biomass burning have been revised downwards. Adipic and nitric acid have been included as additional sources of N_2O. Preliminary analysis of the emissions of volatile organic compounds and sulphur dioxide suggests that the global emissions of these substances are likely to grow in the coming century if no new limitation strategies are implemented.

Table 2: Selected Results of Six 1992 IPCC Greenhouse Gas Scenarios

					Tropical Deforestation		Emissions Per Year					
Scenario	**Years**	**Decline in TPER/GNP** (average annual	**Decline in C intensity** change)	**Cumulative Net Fossil C Emissions** (GtC)	**Total Forest Cleared** (million hectares)	**Cumulative Net C Emissions** (GtC)	**Year**	**CO_2** (GtC)	**CH_4** (Tg)	**N_2O** (TgN)	**CFCs** (Kt)	**SO_x** (TgS)
IS92a	1990-2025	0.8%	0.4%	285	678	42	1990	7.4	506	12.9	827	98
	1990-2100	1.0%	0.2%	1386	1447	77	2025	12.2	659	15.8	217	141
							2100	20.3	917	17.0	3	169
IS92b	1990-2025	0.9%	0.4%	275	678	42	2025	11.8	659	15.7	36	140
	1990-2100	1.0%	0.2%	1316	1447	77	2100	19.1	917	16.9	0	164
IS92c	1990-2025	0.6%	0.7%	228	675	42	2025	8.8	589	15.0	217	115
	1990-2100	0.7%	0.6%	672	1343	70	2100	4.6	546	13.7	3	77
IS92d	1990-2025	0.8%	0.9%	249	420	25	2025	9.3	584	15.1	24	104
	1990-2100	0.8%	0.7%	908	651	30	2100	10.3	567	14.5	0	87
IS92e	1990-2025	1.0%	0.2%	330	678	42	2025	15.1	692	16.3	24	163
	1990-2100	1.1%	0.2%	2050	1447	77	2100	35.8	1072	19.1	0	254
IS92f	1990-2025	0.8%	0.1%	311	725	46	2025	14.4	697	16.2	217	151
	1990-2100	1.0%	0.1%	1690	1686	93	2100	26.6	1168	19.0	3	204

TPER = Total Primary Energy Requirement
Carbon intensity is defined as units of carbon per unit of TPER
CFCs include CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115

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5. Relationship Between Emissions and Atmospheric Concentrations and the Influence on the Radiative Budget

A key issue is to relate emissions of greenhouse gases, greenhouse gas precursors and aerosol precursors to future concentrations of greenhouse gases and aerosols in order to assess their impact on the radiative balance. A number of different types of model have been developed.

Carbon Cycle Models: While there is a variety of carbon cycle models (including 3-D ocean-atmosphere models, 1-D ocean-atmosphere box-diffusion models, and box models that incorporate a terrestrial biospheric sink) all such models are subject to considerable uncertainty because of an inadequate understanding of the processes controlling the uptake and release of CO_2 from the oceans and terrestrial ecosystems. Some models assume a net neutral terrestrial biosphere, balancing fossil fuel emissions of CO_2 by oceanic uptake and atmospheric accumulation, others achieve balance by invoking additional assumptions regarding the effect of CO_2 fertilization on the different parts of the biosphere. However, even models that balance the past and contemporary carbon cycle may not predict future atmospheric concentrations accurately because they do not necessarily represent the proper mix of processes on land and in the oceans.
The differences in predicted changes in CO_2 concentrations are up to 30%. This does not represent the major uncertainty in the prediction of future climate change compared with uncertainties in estimating future patterns of trace gas emissions, and in quantifying climate feedback processes.
A simple empirical estimate can be based on the assumption that the fraction of emissions which remains in the atmosphere is the same as that observed over the last decade; i.e., 46±7%.

Atmospheric Gas Phase Chemistry Models: Current tropospheric models exhibit substantial differences in their predictions of changes in O_3, in the hydroxyl radical (OH) and in other chemically active gases due to emissions of CH_4, CO, non-methane hydrocarbons, and, in particular, NO_x. These arise from uncertainties in the knowledge of background chemical composition and from our inability to represent small-scale processes occurring within the atmosphere. These deficiencies limit the accuracy of predicted changes in the abundance and distribution of tropospheric O_3, and in the lifetimes of a number of other greenhouse gases, including the HCFCs and HFCs, all of which depend upon the abundance of the OH radical. Increases in CH_4, NMHC, and CO all lead to increases in O_3 and decreases in OH, thus leading to an increase in radiative forcing. On the other hand because increases in NO_x lead to an increase in both O_3 and OH, the net effect of NO_x on radiative forcing is uncertain.

Atmospheric Sulphate Aerosol Models: The atmospheric chemistry of sulphate aerosols and their precursors has been extensively studied in relation to the acid rain issue. While our understanding of processes related to chemical transformations has increased significantly in recent years, substantial uncertainties remain, especially regarding the microphysics of aerosol formation, interaction of aerosols with clouds, and the removal of aerosols particles by precipitation.

6. How has our Understanding of Changes in Radiative Forcing Changed?

Since IPCC (1990), there have been significant advances in our understanding of the impact of ozone depletion and sulphate aerosols on radiative forcing and of the limitations of the concept of the Global Warming Potential.

Radiative Forcing due to Changes in Stratospheric Ozone: For the first time observed global depletions of O_3 in the lower stratosphere have been used to calculate changes in the radiative balance of the atmosphere. Although the results are sensitive to atmospheric adjustments, and no GCM studies of the implications of the O_3 changes on surface temperature have been performed, the radiative balance calculations indicate that the O_3 reductions observed during the 1980s have caused reductions in the radiative forcing of the surface-troposphere system at mid-

and high- latitudes. This reduction in radiative forcing resulting from O_3 depletion could, averaged on a global scale and over the last decade, be approximately equal in magnitude and opposite in sign to the enhanced radiative forcing due to increased CFCs during the same time period. The effect at high latitudes is particularly pronounced and, because of these large variations with latitude and region, studies using GCMs are urgently required to further test these findings.

Radiative Forcing due to Changes in Tropospheric Ozone: While there are consistent observations of an increase in tropospheric ozone (up to 10% per decade) at a limited number of locations in Europe, there is not an adequate global set of observations to quantify the magnitude of the increase in radiative forcing. However, it has been calculated that a 10% uniform global increase in tropospheric ozone would increase radiative forcing by about a tenth of a watt per square metre.

Radiative Effects of Sulphur Emissions: Emissions of sulphur compounds from anthropogenic sources lead to the presence of sulphate aerosols which reflect solar radiation. This is likely to have a cooling influence on the Northern Hemisphere (there is negligible effect in the Southern Hemisphere). For clear-sky conditions alone, the cooling caused by current rates of emissions has been estimated to be about 1 $W\ m^{-2}$ averaged over the Northern Hemisphere, a value which should be compared with the estimate of 2.5 $W\ m^{-2}$ for the heating due to anthropogenic greenhouse gas emissions up to the present. The non-uniform distribution of anthropogenic sulphate aerosols coupled with their relatively short atmospheric residence time produce large regional variations in their effects. In addition, sulphate aerosols may affect the radiation budget through changes in cloud optical properties.

Global Warming Potentials: Gases can exert a radiative forcing both directly and indirectly: direct forcing occurs when the gas itself is a greenhouse gas; indirect forcing occurs when chemical transformation of the original gas produces a gas or gases which themselves are greenhouse gases. The concept of the Global Warming Potential (GWP) has been developed for policymakers as a measure of the possible warming effect on the surface-troposphere system arising from the emission of each gas relative to CO_2. The indices are calculated for the contemporary atmosphere and do not take into account possible changes in chemical composition of the atmosphere. Changes in radiative forcing due to CO_2, are non-linear with changes in the atmospheric CO_2 concentrations. Hence, as CO_2 levels increase from present values, the GWPs of the non-CO_2 gases would be higher than those evaluated here. For the concept to be most useful, both the direct and indirect components of the GWP need to be quantified.

Direct Global Warming Potentials: The direct components of the Global Warming Potentials (GWPs) have been recalculated, taking into account revised estimated lifetimes, for a set of time horizons ranging from 20 to 500 years, with CO_2 as the reference gas. The same ocean-atmosphere carbon cycle model as in IPCC (1990) has been used to relate CO_2 emission to concentrations. Table 3 shows values for a selected set of key gases for the 100 year time horizon. While in most cases the values are similar to the previous IPCC (1990) values, the GWPs for some of the HCFCs and HFCs have increased by 20 to 50% because of revised estimates of their lifetimes. The direct GWP of CH_4 has been adjusted upward, correcting an error in the previous IPCC report. The carbon cycle model used in these calculations probably underestimates both the direct and indirect GWP values for all non-CO_2 gases. The magnitude of the bias depends on the atmospheric lifetime of the gas, and the GWP time horizon.

Indirect Global Warming Potentials: Because of our incomplete understanding of chemical processes, most of the indirect GWPs reported in IPCC (1990) are likely to be in substantial error, and none of them can be recommended. Although we are not yet in a position to recommend revised numerical values we know, however, that the indirect GWP for methane is positive and could be comparable in magnitude to its direct value. In contrast, based on the sub-section above, the indirect GWPs for chlorine and bromine halocarbons are likely to be negative. The concept of a GWP for short-lived, inhomogeneously distributed constituents, such as CO, NMHC, and NO_x may prove inapplicable, although, as noted above, we know that these constituents will affect the radiative balance of the atmosphere through changes in tropospheric ozone and OH. Similarly, a GWP for SO_2 is viewed to be inapplicable because of the non-uniform distribution of sulphate aerosols.

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Table 3: Direct GWPs for 100- year Time Horizon

Gas	Direct Global Warming Potential (GWP)	Sign of the Indirect Component of the GWP
Carbon dioxide	1	none
Methane	11	positive
Nitrous oxide	270	uncertain
CFC-11	3400	negative
CFC-12	7100	negative
HCFC-22	1600	negative
HFC-134a	1200	none

Influence of Changes in Solar Output: The existence of strong correlations between characteristics of the solar activity cycle and global mean temperature has been reported. The only immediately plausible physical explanation of these correlations involves variability of the sun's total irradiance on time-scales longer than that of the 11-year activity cycle. Since precise measurements of the irradiance are only available for the last decade, no firm conclusions regarding the influence of solar variability on climate change can be drawn.

WHAT TOOLS DO WE USE AND WHAT INFORMATION DO WE NEED TO PREDICT FUTURE CLIMATE?

Models

The most highly developed tool which we have to model climate and climate change is known as a **general circulation model or GCM**. These models are based on the laws of physics and use descriptions in simplified physical terms (called parametrizations) of the smaller-scale processes such as those due to clouds and deep mixing in the ocean. 'Coupled' general circulation models (CGCMs) have the atmospheric component linked to an oceanic component of comparable complexity.

Climate forecasts are derived in a different way from weather forecasts. A weather prediction model gives a description of the atmosphere's state up to 10 days or so ahead, starting from a detailed description of an initial state of the atmosphere at a given time. Such forecasts describe the movement and development of large weather systems, though they cannot represent very small-scale phenomena; for example, individual shower clouds.

To estimate the influence of greenhouse gases or aerosols in changing climate, the model is first run for a few (simulated) decades. The statistics of the model's output are a description of the model's simulated climate which, if the model is a good one and includes all the important forcing factors, will bear a close resemblance to the climate of the real atmosphere and ocean. The above exercise is then repeated with increasing concentrations of the greenhouse gases or aerosols in the model. The differences between the statistics of the two simulations (for example in mean temperature and interannual variability) provide an estimate of the accompanying climate change.

We also need to determine whether or not the predicted changes will be noticeable above the natural variations in climate. Finally, observations are required in order to monitor climate, to improve the understanding of climate processes and to help in the validation of models.

The long-term change in surface air temperature following a doubling of carbon dioxide (referred to as the **climate sensitivity**) is generally used as a benchmark to compare models. The range of values for climate sensitivity reported in the 1990 Assessment, and re-affirmed in this Supplement, was 1.5° to 4.5°C with a best estimate, based on model results and taking into account the observed climate record, of 2.5°C.

Simpler models, which simulate the behaviour of GCMs, are also used to make predictions of the evolution with time of global temperature from a number of emission scenarios. These so-called box-diffusion models contain highly simplified physics but give similar results to GCMs when globally averaged. Only comprehensive GCMs, however, can provide three-dimensional distributions of the changes in other climate variables, including the changes due to non-linear processes that are not given by simplified models. The extraction of this information from the results of coupled GCMs has only just begun.

Future concentrations of greenhouse gases and aerosols

A necessary starting point for the prediction of changes in climate due to changes in atmospheric constituents is an estimate of their future concentrations. This requires a knowledge of their sources and sinks (natural and man-made) and an estimate of how the strengths of these sources and sinks might change in the future (an **emissions scenario**). The projections of future concentrations can then be used in climate models to estimate the climatic response.

Do GCMs predict future climate?

To make a *prediction* of future climate it is necessary to fulfil two conditions: (a) include all of the major human and natural factors known to affect climate, and (b) predict the future magnitudes of atmospheric concentrations of greenhouse gases. So far, GCMs (and CGCMs) have included only radiative forcing induced by greenhouse gases, and therefore their results relate only to the greenhouse gas component of climate change.

At the time of the 1990 IPCC Report it was recognized that sulphate aerosols exert a significant negative radiative forcing on climate but this forcing was not well quantified. Since then, progress has been made in understanding radiative forcing by sulphate aerosols, and an additional source of negative forcing has been identified in the depletion of stratospheric ozone due to halocarbons. The lack of these negative forcing factors in GCMs does not negate the results obtained from them so far. For example, the estimates of climate sensitivty, which is defined purely in terms of CO_2 concentrations, are unchanged, and it is still believed that anthropogenic greenhouse gases, now and even more so in the future, represent the largest perturbation to the natural radiative balance of the atmosphere. However, it does mean that the rates of change of, say, surface temperature do need to be adjusted for additional forcing factors before they can fulfill condition (a). The second condition is fulfilled when we use a specific prediction (as opposed to a scenario) of future atmospheric concentrations of greenhouse gases.

1992 IPCC SUPPLEMENT: SCIENTIFIC ASSESSMENT

7. Confidence in Model Predictions

There continues to be slow improvement in the ability of models to simulate present climate, although further improvements in the model resolution and the parametrization of physical processes are needed. Since the last report, further evidence has accumulated that atmospheric models are capable of reproducing a range of aspects of atmospheric variability. Coupled ocean-atmosphere models produce variability on decadal time-scales similar in some respects to that observed, and ocean models show longer term fluctuations associated with changes in the thermohaline circulation.

There has been some clarification of the nature of water vapour feedback, although the radiative effects of clouds and related processes continue to be the major source of uncertainty and there remain uncertainties in the predicted changes in upper tropospheric water vapour in the tropics. Biological feedbacks have not yet been taken into account in simulations of climate change.

Increased confidence in the geographical patterns of climate change will require new simulations with improved coupled models and with radiative forcing scenarios that include aerosols.

Confidence in regional climate patterns based directly on GCM output remains low and there is no consistent evidence regarding changes in variability or storminess. GCM results can be interpolated to smaller scales using statistical methods (correlating regional climate with the large-scale flow) or a nested approach (high-resolution, regional climate models driven by large-scale GCM results).
Both methods show promise but an insufficient number of studies have yet been completed to give an improved global picture of regional climate change due to increases in greenhouse gases; in any event both interpolation methods depend critically on the quality of the large-scale flow in the GCM. Given our incomplete knowledge of climate, we cannot rule out the possibility of surprises.

8. Simulated Rates of Change in Climate and their Geographical Distribution.

Results of General Circulation Models (GCMs) available to the 1990 report mainly concerned *equilibrium* simulations. Only one *transient* model run (i.e., where the time-varying response of the climate to steadily increasing greenhouse gas concentrations is simulated) had been completed.

Since then many papers have appeared in the refereed literature concerned with climate models and their results. Significant progress has been made in the area of transient models, with four modelling groups having carried out climate simulations for up to 100 years using coupled ocean-atmosphere global climate models (CGCMs) which incorporate a detailed description of the deep ocean and therefore can simulate the climate lag induced by the deep ocean circulation. These models require substantial adjustments to fluxes of heat and fresh water in order to achieve a realistic simulation of present climate and this may distort the models' response to small perturbations such as those associated with increasing greenhouse gases. For simulations of future climate with these models, carbon dioxide concentrations have been increased at rates close to 1% per year (approximately the equivalent radiatively to the current rate of increase of greenhouse gases).

Internal variability obscures the geographical patterns of change during the first few decades of the experiments. However, once these patterns become established, they vary relatively little as the integrations progress and are similar to those produced by equilibrium models in a number of ways, for instance:

(i) surface air temperatures increase more over land than over oceans;
(ii) precipitation increases on average at high latitudes, in the monsoon region of Asia and in the winter at mid-latitudes;
(iii) over some mid-latitude continental areas values of soil moisture are lower on average in summer.

The transient CO_2 simulations, however, show that over the northern North Atlantic and the southern oceans near Antarctica the warming is reduced by 60% or more relative to equilibrium simulations at the time of doubling CO_2.

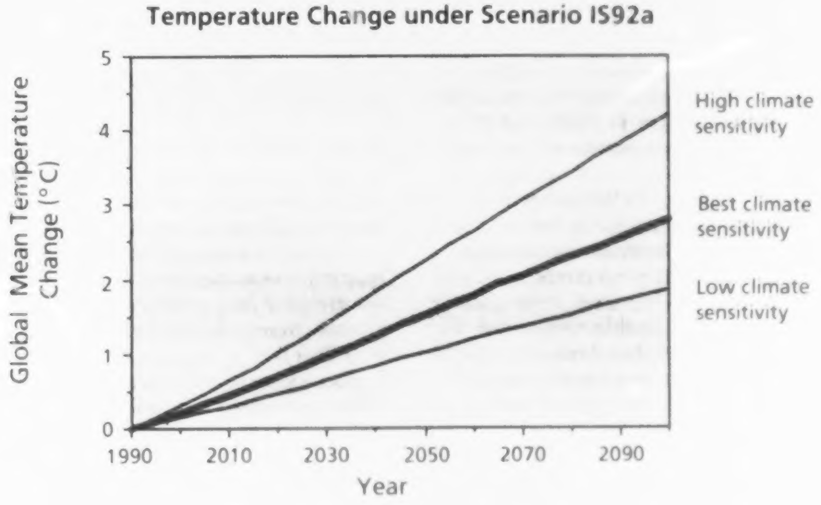
Much further development and validation of coupled models is required.

9. What Would We Now Estimate for Climate Change?

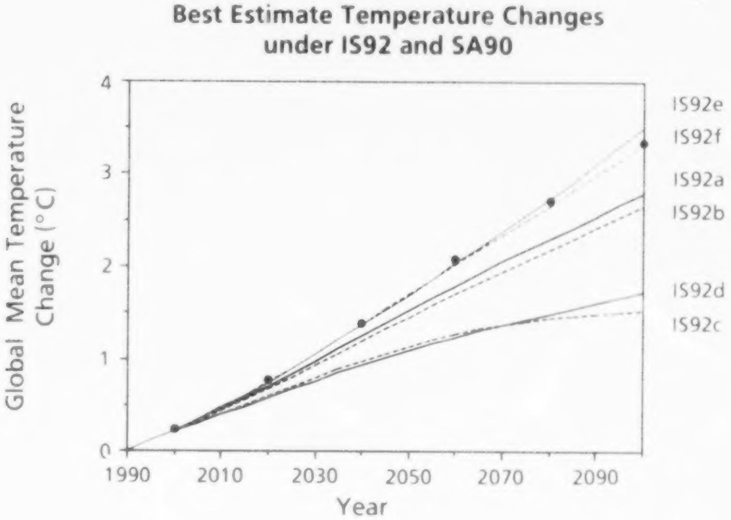
The new simulations using coupled ocean-atmosphere GCMs, which do not include the effects of sulphates and ozone depletion, generally confirm the IPCC 1990 estimates of future warming at rates of about 0.3°C/decade (range 0.2 to 0.5°C/decade) over the next century for IPCC 1990 Scenario A. Because GCMs do not yet include possible opposing anthropogenic influences, including the forcing from sulphate aerosols and stratospheric ozone depletion, the net rate of increase in surface temperature is expected to be less, at least during the period for which sulphur emissions continue to increase, than would be expected from greenhouse gas forcing alone. However, the globally averaged magnitude of the effect of sulphate aerosols has not yet been calculated accurately and further work is needed.

The simulated rate of change of sea level *due to oceanic thermal expansion only* ranges from 2 to 4 cm per decade, again consistent with the previous report.

New IPCC 1992 emissions scenarios (IS92a-f; see Section 4) have been derived in the light of new information and international agreements. In order to provide an initial assessment of the effect of the new scenarios, the change in surface temperature has been estimated with the simple climate model used in the IPCC 1990 report which has been calibrated against the more comprehensive coupled ocean-atmosphere models (see box on models). These calculations include, in the same way as did the 1990 calculations, the direct radiative forcing effects of all the greenhouse gases included in the scenarios. The effect of stratospheric ozone depletion and of sulphate aerosols have not been included, which again parallels the 1990 calculations. The accompanying diagrams show (i) the temporal evolution of surface temperature for IS92a, assuming the high, "best estimate" and low climate sensitivities (4.5, 2.5 and 1.5°C), and (ii) the temperature changes for the six 1992 IPCC scenarios and the 1990 Scenario A, assuming the "best estimate" of climate sensitivity (see earlier box on "What tools do we use ....?" for the definition of climate sensitivity).



Estimates of global mean temperature change for IS92a using high (4.5 °C), "best estimate" (2.5 °C), and low (1.5 °C) values of climate sensitivity. The effects of sulphate aerosol and ozone depletion have not been taken into account



Estimates of global mean temperature change for the IPCC 1992 scenarios (IS92a-f) assuming the IPCC "best estimate" climate sensitivity. The effects of sulphate aerosol and ozone depletion have not been taken into account. SA90 is represented by solid circles.

10. The Updated Record of Global Mean Temperatures

Continuing research into the 19th century ocean temperature record has not significantly altered our calculation of surface temperature warming over the past 100-130 years of 0.45±0.15°C. Furthermore, global surface temperatures for 1990 and 1991 have been similar to those of the warmest years of the 1980s and continue to be warmer than the rest of the record. The research has, however, led to a small adjustment in hemispheric temperatures. The long-term warming trends assessed in each hemisphere are now more nearly equal, with the Southern Hemisphere marginally warmer in the late nineteenth century and the Northern Hemisphere trend unchanged from previous estimates.

A notable feature over considerable areas of the continental land masses of the Northern Hemisphere is that warming over the last few decades is primarily due to an increase of night-time rather than daytime temperatures. These changes appear to be partly related to increases in cloudiness but other factors cannot be excluded such as a direct cooling effect of aerosols on maximum temperatures in sunny weather, an influence of increasing concentrations of greenhouse gases and some residual influence of urbanisation on minimum temperatures. A more complete study is needed as only 25% of the global land area has been analysed. In this regard, regional changes in maximum, minimum and mean temperature related to changes in land use (e.g., desertification, deforestation or widespread irrigation) may need to be identified separately.

A new source of information that supports higher sea surface temperatures in many tropical regions over the last decade concerns evidence that the bleaching of tropical corals has apparently increased. Bleaching has been shown to be related (in part) to episodes of sea surface temperature warmer than the normal range of tolerance of these animals, though increasing pollution may be having an influence.

There has been considerable interest in mid-tropospheric temperature observations made since 1979 from the Microwave Sounding Unit (MSU) aboard the TIROS-N satellites. The MSU data have a truly global coverage but there is only a short record (13 years) of measurements; the surface and the radiosonde data are less spatially complete but have much longer records (over 130 and near 30 years, respectively). Globally-averaged trends in MSU, radiosonde and surface data sets between 1979 and 1991 differ somewhat (0.06, 0.17, and 0.18°C per decade, respectively), although the differences are not statistically significant. Satellite sounders, radiosonde and surface instruments all have different measurement characteristics and, in addition, geographical and temporal variations in mid-tropospheric and surface temperatures are not expected to be identical. Despite this, correlations between global annual values of the three data sets are quite high.

Note that it is not possible to rank recent warm years in an absolute way; it depends on which record is used, what level is referred to and how much uncertainty is attached to each value.

MSU data have been able to detect the impact on lower stratospheric temperature of volcanic eruptions in a striking way. Variability in these data between 1979 and 1991 is dominated by short-term temperature fluctuations (greatest in the tropics) following the injection of large amounts of aerosol into the stratosphere by the eruptions of El Chichon (1982) and Mt. Pinatubo (1991). Globally, temperature rises in the lower stratosphere were about 1°C and 1.3°C respectively; stratospheric warming due to El Chichon lasted nearly two years while that due to Mt. Pinatubo is still underway. The longer radiosonde record, however, shows a significant global cooling trend of about 0.4°C per decade since the middle 1960s in the lower stratosphere.

11. Are There any Trends in Other Climatically Important Quantities?

Precipitation variations of practical significance have been documented on many time- and space-scales, but due to data coverage and inhomogeneity problems nothing can be said about global-scale changes. An apparent increase of water vapour in the tropics parallels the increase in lowe tropospheric temperature but it is not yet possible to say to what extent the changes are real and whether they are larger than natural variability.

A small, irregular, decrease of about 8% has been observed in annually averaged snow cover extent over the Northern Hemisphere since 1973 in a new, improved, compilation of these data. The reduction is thought to be real because annual values of snow cover extent and surface air temperatures over the extratropical Northern Hemisphere land have a high correlation of -0.76.

There is evidence that, regionally, relatively fast (sometimes called abrupt) climate changes can occur. These changes may persist for up to several decades but are often a function of season. These fast changes are poorly understood, but can be of considerable practical importance.

12. Are the Observed Temperature Changes Consistent with Predicted Temperature Changes?

CGCMs, which do not yet take into account changes in aerosols, predict a greater degree of warming in the Northern Hemisphere (NH) than in the Southern Hemisphere (SH), a result of the greater extent of land in the NH which responds more rapidly to forcing. The observed larger warming of the SH in recent decades (0.3°C between 1955 and 1985) than in the NH (which hardly warmed at all over the same period) is at first sight in conflict with this prediction. Recently, however, the NH has started to warm quite rapidly. The reasons for the differences in observed warming rates in the two hemispheres are not known though man-made aerosols (see Section 6) and changes in ocean circulation may have played a part.

Furthermore, increases in CFCs may have reduced ozone levels sufficiently to offset in a globally-averaged sense the direct greenhouse effect of CFCs. Consequently, the estimates of warming over the last 100 years due to increases in greenhouse gases made in the original report may be somewhat too rapid because they did not take account of these cooling influences. Taking this into account could bring the results of model simulations closer to the observed changes.

Individual volcanic eruptions, such as that of El Chichon, may have led to surface cooling over several years but should have negligible effect on the long-term trend. Some influence of solar variations on time-scales associated with several sunspot cycles remains unproven but is a possibility.

The conclusion of the 1990 report remains unchanged:

> *"the size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability, alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming".*

13. Key Uncertainties and Further Work Required

The prediction of future climate change is critically dependent on scenarios of future anthropogenic emissions of greenhouse gases and other climate forcing agents such as aerosols. These depend not only on factors which can be addressed by the natural sciences but also on factors such as population and economic growth and energy policy where there is much uncertainty and which are the concern of the social sciences. Natural and social scientists need to cooperate closely in the development of scenarios of future emissions.

Since the 1990 report there has been a greater appreciation of many of the uncertainties which affect our predictions of the timing, magnitude and regional patterns of climate change. These continue to be rooted in our inadequate understanding of:

- sources and sinks of greenhouse gases and aerosols and their atmospheric concentrations (including their indirect effects on global warming)
- clouds (particularly their feedback effect on greenhouse-gas-induced global warming, also the effect of aerosols on clouds and their radiative properties) and other elements of the atmospheric water budget, including the processes controlling upper-level water vapour
- oceans, which through their thermal inertia and possible changes in circulation, influence the timing and pattern of climate change
- polar ice sheets (whose response to climate change also affects predictions of sea level rise)
- land surface processes and feedbacks, including hydrological and ecological processes which couple regional and global climates.

Reduction of these uncertainties requires:

- the development of improved models which include adequate description of all components of the climate system
- improvements in the systematic observation and understanding of climate-forcing variables on a global basis, including solar irradiance and aerosols
- development of comprehensive observations of the relevant variables describing all components of the climate system, involving as required new technologies and the establishment of data sets
- better understanding of climate-related processes, particularly those associated with clouds, oceans and the carbon-cycle
- an improved understanding of social, technological and economic processes, especially in developing countries, that are necessary to develop more realistic scenarios of future emissions
- the development of national inventories of current emissions
- more detailed knowledge of climate changes which have taken place in the past
- sustained and increased support for climate research activities which cross national and disciplinary boundaries; particular action is still needed to facilitate the full involvement of developing countries
- improved international exchange of climate data.

Many of these requirements are being addressed by major international programmes, in particular by the World Climate Research Programme (WCRP), the International Geosphere Biosphere Programme (IGBP) and the Global Climate Observing System (GCOS). Adequate resources need to be provided both to the international organization of these programmes and to the national efforts supporting them if the new information necessary to reduce the uncertainties is to be forthcoming. Resources also need to be provided to support on a national or regional basis, and especially in developing countries, the analysis of data relating to a wide range of climate variables and the continued observation of important variables with adequate coverage and accuracy.

ANNEX

Progress in the Development of an IPCC Methodology for National Inventories of Net Emissions of Greenhouse Gases

Scientific assessment is primarily concerned with sources and sinks at the global, and large region level but, in order to support national and international responses to climate change, it is necessary to estimate emissions and sinks at the national level in an agreed and consistent way.

IPCC (1991) has established a work programme to:

- (i) develop an approved detailed methodology for calculating national inventories of greenhouse gas emissions and sinks
- (ii) assist all participating countries to implement this methodology and provide results by the end of 1993.

This programme is based on preliminary work sponsored by the Organization for Economic Cooperation and Development (OECD, 1991). OECD and the International Energy Agency (IEA) are continuing to provide technical support to the IPCC work programme. The programme will manage the development and approval of inventory methods and procedures, and the collection and evaluation of data. It will collaborate with other sponsors including the Global Environment Facility (GEF), the Asian Development Bank, the European Community, UNECE and individual donor countries, to encourage funding of technical cooperation projects in greenhouse gas (GHG) inventories.

The IPCC requested that participating countries provide any available GHG emissions inventory data to the IPCC by the end of September 1991. As of January 1992, 18 countries have submitted complete or partial GHG inventories (see Table overleaf); most relate to average emissions over one, two or three years in the period 1988 to 1990. This process has been particularly useful in identifying problems in coverage and consistency of currently available inventories.

An IPCC Workshop on National GHG Inventories, held in Geneva from 5-6 December 1991, provided guidance on needed improvements in the draft methodology and priorities for the work programme. Numerous improvements to the methodology were agreed upon, and priorities were proposed for the work programme and for technical cooperation activities. As a result of the preliminary data collection, the workshop, and other comments received, the following major priorities for the IPCC work programme have been established:

Methodology

- Develop a simpler methodology and streamlined "workbook" document to assist users in its implementation
- Work with experts to develop a new and simpler method for calculating CO_2 emissions from forestry and land-use change
- Establish technical expert groups to improve the methodology for CH_4 from rice and fossil fuel production, and other key gases and source types
- Work with experts to include halocarbons in the GHG inventory starting with data available from the Montreal Protocol process

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Dealing with Scientific Uncertainty: the Educational Challenge

Governmental policies or programs that are adopted need the strong support and actions of everyone in order to be successful. However, many individuals do not have a good understanding of the complex issues, problems, and potential impacts of global change or they are confused by the conflicting, alarmist information of the mass media. Also, unlike what has happened in the research community, there has not been a large infusion of public funds for a coordinated, integrated, and interdisciplinary education effort. As a result many informational activities are disjointed, and may be based more on emotion than fact. (Spranger, 1990).

There is a need for the public to receive accurate, objective scientific information about global change and its implications. Not only do they need to understand the basic science, processes, and impacts of global change, but they also need to understand how collective and local actions can be taken to respond to this issue. Hundreds of scientists from around the world who are working on this issue, as part of the International Panel of Climate Change under the direction of the United Nation's Environmental Programme, unanimously agree on this point. (Titus, 1990).

Envisioned by such eigtheenth - century philosophers as Jean Jacques Rousseau, John Locke, and John Stuart Mill, government requires that everyone has the right to influence political decisions that affect them. A basic assumption is that everyone is - or should be - essentially equal, in both their concern for public issues and their competency to make decisions about them. However, in order to make these decisions, individuals need accurate and understandable information. Unfortunately, many articles on global change are either sensational, too technical, or too abstract for the student and the general public, or they do not provide a connection between their everyday actions and the impending long-term global changes that may take place.

In addition, in the classroom many science educators may teach the "science" of the issue, but fail to give the issue an interdisciplinary focus which also discusses the socio-economic-political elements and ethical considerations. And many social science teachers may talk about the socio-economic-political problems, but lack the scientific education and technical information needed to explain the "science" and how these issues may be resolved. Those educators involved in informal adult education face the same dilemma.

Also, we can point our fingers at the entire educational process on our current dilemma. In the February 25, 1991 issue of Newsweek Magazine an article was printed on "why my kids hate science". The author pointed out that our educational system provides a process where we cull out non-scientists. We tend to discard those students that are not initially turned on by science...and focus on the brighest and the best, or those that society deems are not suited to the scientific professions. For example, at one time the educational system only focused on males....women could not become scientists because their place was in the home. A similar indictment can be made for minorities today.

So we have become a nation of scientifically illiterate people. But remember, who makes the social decisions on local, regional, and national levels involving science and emerging technologies. and their budgets! It's all of us. Individuals turned off by science, or confused about the uncertainty that may exist over an environmental issue may not be supportive of sicnece and its importance in dealing with the global environmental issues of today. So it's up to all of us to provide our students (whether it be in the formal or informal setting) with some basic understanding about the role and utility of science as we grapple with these highly complex issues.

How Do We Acquire Our Values?

Each one of us holds and acts on a number of values; some are relatively unimportant, because they are temporal or arise from relatively insignificant desire (e.g. a preference for a certain type of automobile). However, each of us has certain values that are very important to us. These are values that are central to our being, providing the basis of our character, self-conceptions, and belief systems.

Since we live in a pluralistic society, we have different values which often clash, and are resolved in the social-economic-political world in which we live. We need to understand how we receive these values. Individual values are derived from a variety of sources: family and cultural influences; "influentials " (teachers, friends, pastor, etc.); life experiences; professional training and standards; employment; etc.

Hunter Lewis in 1990 wrote a book called A Question of Values: Six Ways We Make the Personal Choices That Shape Our Lives. In this book, Lewis lays out a framework describing how we develop and choose our values. Lewis points out that we have at least six profoundly different cognitive lenses through which we view the world, and thus different styles for thinking by which we make our value judgments, our ethical decisions.

These six "lenses" help us choose (or learn about) our values) according to Lewis. These can be found on the following page. You may not totally agree with this typology; but it does present us with a framework upon which to make us conscious of our values. And it is important to recognize that ethical behavior is conscious behavior. Scott Peck, author of The Road Less Traveled, points this out in commenting about Lewis's ideas.

> ...Ethical behavior is, of necessity, conscious behavior. If we are unconscious of our motives, it is unlikely that we will behave in a consistently ethical manner. If we are not aware of the particular lens through which we are looking at the world, then we do not have any true choice about what we are going to see and how we are going to respond...
>
> M. Scott Peck

Peck also points out that if we are conscious about our values and the range of values, then two results are possible. One is that we can begin to question the validity of our perceptions and values, for the capacity for ethical behavior is dependent on the capacity for such self-questioning. He states that virtually all of the evil in this world is committed by people who are absolutely certain they know what they are doing.

The other result is that it enables us to begin to make multi-dimensional rather than one-dimensional simplistic decisions. If we think just logically or emotionally or intuitively, then our decisions will be only logical or only intuitive or only emotional. But if we become aware of the variety of different cognitive styles, it opens up the possibility for us to make decisions that are emotional and logical and intuitive. In other words, such consciousness makes it possible for us to integrate different ways of knowing—to think, so to speak, with both our right brain and our left brain. Value clashes will probably still occur, but we will, at least, have some insight in where they are coming from.

Six Methods by Which We Acquire Our Values

1) Authority	Taking someone else's work, having faith in an external authority. (e.g. having faith in church or the Bible)	I have faith in the authority of
2) Logic	Subjecting beliefs to the variety of consistency tests that underlie deductive reasoning.	Since A is true, B must be true because B follows A
3) Senses	Gaining direct knowledge through our own five senses	I know it's true because I saw it, I heard it, I tasted it, I smelled it, or I touched it.
4) Emotion	Feeling that something is right: although we do not usually associate feeling with thinking or urging, we actually "think" and "judge" through our emotions all the time.	I feel that it is true
5) Intuition	Unconscious thinking that is not emotional.	After struggling with this problem all day, I went to bed confused and exhausted. The next morning, when I woke up, the solution came to me in a flash and I just knew it was true.
6) "Science"	A synthetic technique relying on sense experience to collect observable facts; intuition to develop a testable hypothesis about the facts; logic to develop the test (experiment); and sense experience again to complete the test.	I tested the hypothesis experimentally and found that it was true.

Values and Environmental Politics

Questions that each one of us must ask are: If Earth and its resources are being threatened as we are discovering, why do we continue to abuse them? Why do these problems continue, and why does it appear that nothing is being done? Values and politics are the crux of the problem, and part of the solution. The answer lies in understanding the role of and environmental politics. Any collective or individual action either to protect or exploit the environment is guided by values.

We should begin by understanding the individual value system and how it relates to the social world in which we live and in which decisions are made. Our thinking and actions are based on the values and beliefs we have developed individually and collectively. These often clash, and are resolved in the social-economic-political world in which we live. People's differing values about the environment are evident in four major philosophies of natural resource management —utilitarianism, progressive conservation, environmentalism, and romantic preservation—that exist in the United States today. Each philosophy consists of beliefs and values about natural resource management goals and optimal ecological conditions. Each reflects an underlying political philosophy, a set of values about how political processes should or do affect those management goals and ecological conditions, (Culhane, 1981).

Utilitarianism------Progressive Conservation------Environmentalism------Preservation

(Use-Oriented) (Biocentric)

Figure 1. Natural Resource Philosophy Continuum (From Culhane, 1981 p. 10)

These philosophies can be viewed as a continuum (Figure 1), with varying degrees of emphasis on human consumption use and biosphere maintenance. A pure utilitarian is concerned solely with the human use of earth's resources, irrespective of the wider consequences. Although most people will not readily admit to being a pure utilitarian today, we do have some recent examples around the world today, exhibited by the destruction of tropical rainforests by multi-national companies in the name of profit.. The conservationist is committed to use, but attempts to reconcile it with biological constraints: to maintain productivity, it is prudent to respect the biosphere. Multiple use is the underlying premise, first proposed by Gifford Pinchot in the early 1900s, and carried out today by such agencies as the U.S. Forest Service and U.S. Army Corps of Engineers.

The environmentalist is committed to maintaining the integrity of the biosphere: as a part of the biosphere, humankind must not imperil it; maintenance of humankind's existence is a secondary benefit, and the continuation of mankind's ability to use the biosphere is a tertiary benefit. Such individuals as Aldo Leopold, Garrett Hardin, and Barry Commoner would espouse this philosophy. The preservationist wishes to protect parts of the biosphere from human use, irrespective of the possible benefits of that use for humans. This view was aptly expressed by Henry David Thoreau, and today is being espoused by The Wilderness Society.

The Role of Science and Politics in Decision-making

Many individuals feel that science is "value-free" and can resolve our environmental problems. However, scientists are also not immune to clashing values. Experts with the same education, professional training, standards, and "facts" often disagree about the impact, severity, and solution to our environmental issues. Why? This is because of conflicting/differing values. Scientists may disagree on values just like everyone else. Their base value may not be totally lodged within science principles; they may also be imbued with authority, logic, senses, emotion, or intuition values (following Hunter Lewis' typology of values).

Scientists may differ on the "facts" and courses of action we should take based on how much risk they are willing to accept, both for themselves and future generations. We must also remember that scientists may disagree on the "science" because scientific "truth" is not a static, closed entity, but rather is an evolving and self-correcting process. Thus, we must remind ourselves that science is a useful tool which can illuminate the issues, impacts, and possible solutions to public problems, but science cannot resolve them. The choice of solutions is ours to make, either individually or collectively in the social world in which we live.

The kind of planet and global ecosystem we want is ultimately a question of values and ethics. How much species diversity should be maintained? Should size/growth rate of human population be curtailed to protect the global environment? If so, how much? How much climate change is acceptable? How much poverty? How much energy use/waste? These value choices and decisions are ultimately made in the political arena. Our values, guided through individual and institutional interactions, determine the role, scope, and actions of government to protect, conserve, utilize, or exploit our environment.

Rather than suggest that we are forever in a political stalemate due to differing values, sometimes our values do coalesce and things do get accomplished on a societal level. The result is a "political breakthrough." With such a consensus government, resources, and societal actions can work together to resolve problems. We have several examples of breakthroughs in the United States over the past 50 years. In the 1930s, individual values coalesced into the "New Deal," from which major new social programs were created. In the 1960s, the civil rights movements swept throughout American society. In the 1970s, individual values coalesced into the environmental movement, with many environmental laws passed.

Some political commentators appear very optimistic about our values and attitudes toward the environment. They feel that environmental matters are receiving much more attention today than in the past. They suggest that the most significant change in the politics of the 1990s is that environmental protection has moved from the margins into the mainstream of national political life. (Vig and Kraft, 1991)

Others suggest that our values may be coalescing into a new global political breakthrough in the 1990s. Many global environmental laws and regulations are emerging to go along with the increasing global consciousness that is now taking place (John McCormick, 1990). We may be at a period in human social thought where leading thinkers from all cultures will join to address the ethics of the environment and development as one unified subject and in a global perspectives (Engel, 1990). Although some people are pessimistic about the recent Rio de Janeiro Environmental Summit meetings it does appear that a new worldwide consciousness about the environment may be emerging. Decision-makers are now making treaties and international agreements dealing with these global issues. Only time will tell if these actions result in significant decisions that positively impact the environment and world in which we all live.

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CHRONOLOGY OF GLOBAL CLIMATE CHANGE

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It is well known and accepted, at both the scientific and the popular level, that global-scale climate changes occur very gradually over long periods of time. Scientists have documented the gradual fluctuations by identifying changes in soil layers and rocks, and bubbles trapped in glacial ice.

However, there is increasing evidence that human activities may be accelerating this natural phenomenon. Over the years, humans have changed rivers, seas, forests, and soils; expanded the amount of land covered by cities, highways and farms; and increased the amount of gases discharged into the atmosphere.

Some recent studies reveal a slow rise in the average earthly temperature over the last 100 years. Now, scientists are challenged to determine whether this climate channge is actually occurring, how much of this change is occurring naturally, and to what extent human activities are contributing to and accelerating the changes.

The following provides a historical perspective of events leading to the world's current awareness of global climate change.

Early 1800's	The Industrial revolution begins in Great Britain, spreading around the developed world. Fossil fuels like peat, coal and, later, oil used to power industry.
1863	John Tyndall, British scientist, describes how water vapor in the atmosphere helps to keep the world warm.
1896	Svante Arrhenius, a Swedish chemist, warns that carbon dioxide (CO_2) released to the atmosphere from burning coal for industrial power is likely to make the world warmer.

1930	An American engineer, Thomas Midgley, proposes using new chlorofluorocarbons (CFCs) instead of poisonous ammonia for cooling refrigerators.
1957	International Geophysical Year. Regular monitoring of atmospheric CO_2 begins in Hawaii and Antarctica.
1970's	Climatologists with high-speed computers begin projecting warming of 3 to 9 degrees by the end of the 21st century, based on carbon dioxide emissions.
1985	At an October meeting, scientists from 19 countries agree with a study crediting other trace gases, including CFCs, with adding as much to the greenhouse effect as CO_2.
1987	Global Climate Protection Act, P.L. 100-204, becomes law. Montreal Convention is held to consider how to limit atmospheric pollution by CFCs.
1987	Our Common Future, known as the Brundtland Report after its chairman, Gro Harlem Brundtland, publishes the findings of the World Commission on Environment and Development. While its conclusions do not please all environmental experts, it is a major information resource and rallying point.
1987-1988	Drought, fires, and severe heat waves arouse public anxiety and conjecture that they are first signs of global warming.
1988	Intergovernmental Program on Climate Change (IPCC) is convened in Geneva for the first time.
1989	Seventy-one nations, meeting in The Netherlands, agree to a Declaration on Atmospheric Pollution and Climatic Change.
1990	At the fourth meeting of the IPCC in Sweden, the United States join 73 other nations in agreeing that humans' activities are causing the Earth's atmosphere to heat up.
1991	President Bush hosts a climate change treaty negotiating session in Chantilly, VA, in February.
1991	United Nations environment conferences are held in Nairobi, Kenya in June and in Geneva, Switzerland in September.
1992	In June, the world focuses its attention on the "Earth Summit," the United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil. Treaties and agreements which are negotiated, and signed by leaders of many countries, may lead to more sensitive use of the planet's diminishing resources.

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THE CHA E
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by Michael S. Spranger

The potentially devastating impact of human activity on the global environment has become one of the major international issues of the 1990s. You cannot pick up a newspaper or view a television newscast today without seeing at least one story devoted to this issue. These stories focus on such problems as: threats to the climate and damage to our populated coasts and social infrastructure due to sea-level rise resulting from greenhouse warming:

- damage to plant, animal and human health from increased ultraviolet radiation due to the depletion of stratospheric ozone;
- species extinction due to tropical deforestation;
- threats to marine life and human recreation from coastal and estuarine pollution;
- human, animal, and environmental damage and contamination from nuclear and hazardous waste;
- damage to lakes and forests from acid rain, and
- the human population explosion, with its accompanying themes of poverty, famine, and death.

Many are now proclaiming that global environmental change in its many forms is the new battle cry around the world, (Abrahamson, 1989; Schneider, 1989; Roan, 1989; Brown, 1990).

However, global environmental change is not a new phenomenon. Since the dawn of creation, the earth and its resources, the climate and the atmosphere have been continuously changing since they constitute a dynamic system. But what is unique is the accelerated changes and the possible devastating impacts to the environment—the result of human actions over the last 100 years in realizing the Industrial and Post-Industrial Revolution. For the first time human, technology now has the capability of radically altering the global ecosystem.

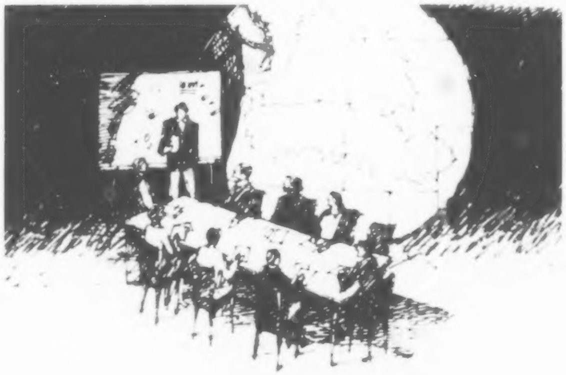
Why this renewed focus on the environment by the public media? There are several reasons. Major climatic events of the late 1980s—droughts, hurricanes, major floods, evidence of holes in the ozone layer—brought print exposure, television air time, and international attention to global environmental issues. Also, scientists and teachers in the 1980s began to step beyond their laboratories and classrooms to discuss the ramifications of rapid global change in the public arena which caught the attention of the media and our governmental officials. The result has been a new consciousness on the accelerated changes in Earth's systems due to human influence.

The scientific community has embarked on a new research plane that is integrated, coordinated, interdisciplinary, and international in scope. Billions of dollars are being spent on research to increase our knowledge on global change issues. Technological and scientific advances are giving us the ability to measure, model, and predict more accurately what is happening within the earth's dynamic systems. But there still is much that is unknown. Currently there is considerable debate within the scientific community about "facts" and potential impacts of global change. Despite the scientific debate, the paucity of information, and the uncertainty of future climatic events, national and international decisions and policies are being made to deal with the global climate change issues.

The Educational Challenge

Governmental policies or programs need the strong support and actions of everyone in order to be successful. To date, many individuals do not have a good understanding of the complex issues, problems, and potential impacts of global change, or they are confused by the conflicting, alarmist information presented by the media. Also, unlike what has been happening in the research community, there has not been a large infusion of public funds for a coordinated, integrated, and interdisciplinary education effort. As a result, many informational activities that have occurred have been disjointed, and based more on emotion than fact, (Spranger, 1990) .

Both students and adults need to receive accurate, objective scientific information about global change and its implications. Not only do they need to understand the basic science, processes, and impacts of global change, but they also need to understand how collective and local actions can be taken to respond to this issue. Hundreds of scientists from around the world who are working on this issue, as part of the International Panel of Climate Change under the direction of the United Nation's Environmental Programme, unanimously agree on this point. (Titus, 1990).



Envisioned by such 18th-century philosophers as Jean Jacques Rousseau, John Locke, and John Stuart Mill, government requires that everyone has the right to influence political decisions that affect them. A basic assumption is that everyone is—or should be—essentially equal, in both their concern for public issues and their competency to make decisions about them. However, in order to make these decisions, individuals need accurate and understandable information. Unfortunately, many articles on global change are either sensational, technical, or too abstract for the student and the general public, or they do not make a connection between our everyday actions and the impending long-term global changes that may take place.

Additionally, many science educators may teach the "science" of the issue, but may fail to give the issue an interdisciplinary focus which also looks at the socio-economic-political elements as well as ethical considerations. And many social science teachers may talk about the socio-economic-political problems, but lack the scientific education and technical information needed to explain the "science" and how these issues may be resolved. Those educators involved in informal adult education face the same dilemma.

Environmental Politics

Questions each one of us must ask include: if Earth and its resources are being threatened, why do we continue to abuse them? Why do these problems continue, and why does it appear that nothing is being done? The answers lie in understanding the role of values and environmental politics. Any collective or individual action, either to protect or exploit the environment, is guided by values. These values often compete with each other. And these values, articulated through human debate and institutional interactions, ultimately determine the role and scope of government in environmental affairs. (Henning and Mangun, 1989).

Educators need to understand the individual value system and how it relates to the social world in which we live and in which environmental decisions are made. Our thinking and actions are based on the values and beliefs that have developed individually and collectively. Since we live in a pluralistic society, these often clash, and are resolved in the social-economic-political world in which we live. One writer has categorized differing individual values about the environment into four major philosophies of natural resource management—utilitarianism, conservationism, environmentalism, and preservationism. Each philosophy consists of beliefs and values about natural resource management goals and optimal ecological conditions. Each also reflects an underlying political philosophy, a set of values about how political processes should or do affect those management goals and ecological conditions, (Culhane, 1981).

These philosophies can be viewed as a continuum (Figure 1), with varying degrees of emphasis on human consumption use and biosphere maintenance.

Figure 1. Natural Resource Philosophy Continuum

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Utilitarianism

Conservationism

Environmentalism

Preservationism

BIOCENTRIC

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- **Utilitarianism**—A pure utilitarian is concerned solely with the human use of earth's resources, irrespective of the wider consequences. Although most people will not readily admit to being a pure utilitarian today, there are recent examples of extreme use and exploitation of our resources, such as former Secretary of the Interior James Watt, who tried to carry out his "Sagebrush Revolution" policies during the Reagan administration in the mid-1980s.
- **Conservationism**—The conservationist is committed to use of the natural resources, but attempts to reconcile it within biological constraints. It is prudent to respect the biosphere and maintain productivity, in order to have continued use of the resource. Multiple use of our natural resources is the underlying premise as first proposed by Gifford Pinchot in the early 1900s. Today this philosophy is carried out by the U.S. Forest Service in our national forests, and by the U.S. Army Corps of Engineers with our water resources.
- **Environmentalism**—The environmentalist is committed to maintaining the integrity of the biosphere; humankind must not imperil it. Maintenance of humankind's existence is a secondary benefit, and the continuation of humankind's ability to use the biosphere is a tertiary benefit. Such individuals as Aldo Leopold, Garrett Hardin, and Barry Commoner would espouse this philosophy.
- **Preservationism**—The preservationist is committed to protection of the biosphere, and sees that parts of the biosphere are unique in their own way and should have limited human use, irrespective of the possible benefits of that use for humans. This view was aptly expressed by Henry David Thoreau, and today is espoused by such groups as The Wilderness Society.

In addition to understanding these differences in environmental management philosophies, educators need to understand how individual values are developed, since they are important in determining environmental decisions. Each of us holds and acts on a number of values; some are relatively unimportant, because they are temporal or arise from relatively insignificant desires (e.g. a preference for a certain type of automobile).

However, each of us also has certain values that are very important to us. These are values that are central to our being, providing the basis of our character, self-conceptions, and belief systems. These have been called Individual Overriding values (IORVs). IORVs have high priority in our belief system, and are stable over time. They are "overriding" in that they are used to override lesser values, and to resolve conflicts within our values when they occur. Sometimes there may be conflicts within our IORVs. When this occurs, we may have to choose between two "goods," two "evils," or two duties. We may be uncomfortable, but we do it (Paris & Reynolds, 1983). These IORVs are the result of many variables: family and cultural influences, impact of "influentials" when we are growing up, professional training and standards, employment, etc. Since our life experiences differ, our IORVs will necessarily differ. Our IORVs serve as our basic frame of reference in viewing our place on Earth. The problem is that often these IORV s collide with those of other people. Because we have clashing IORVs, they tend to cancel each other out in our pluralistic, democratic society. This is why nothing appears to get done by government to resolve pressing problems.

Scientists are also not immune to clashing IORVs. Experts with the same education, professional training, standards, and "facts" regarding global change often disagree. Why? This is because of conflicting/differing IORVs. Scientists may disagree on values just like everyone else. We must also remember that scientists may disagree on the "science" because scientific "truth" is not a static, closed entity, but rather is an evolving and self-correcting process. Thus, we must remind ourselves that science is a useful tool which can illuminate the issues, impacts, and possible solutions to public problems, but science cannot resolve them. The choice of solutions is ours to make, either individually or collectively in the social world in which we live.

The kind of planet and global ecosystem we want is ultimately a question of values. How much species diversity should be maintained? Should size/growth rate of human population be curtailed to protect the global environment? If so, how much? How much climate change is acceptable? How much poverty? How much energy use/waste? These value choices and decisions are ultimately made in the political arena. Our IORVs, guided through individual and institutional interactions, determine the role, scope, and actions of government to protect, conserve, utilize, or exploit our environment.

Rather than suggest that we are forever in a political stalemate due to differing IORVs, often IORVs do coalesce into what has been termed a social overriding value (SORV), and things do get accomplished on a societal level. The result is a "political breakthrough." With such a consensus, government, resources, and societal actions work together to resolve problems. We have several examples of breakthroughs in the past 50 years. In the 1930s, IORVs coalesced into the "New Deal," from which major new social programs were created. In the 1960s, the civil rights movement swept throughout American society. In the 1970s, IORVs coalesced into the environmental movement, and many new environmental laws were created.

In the 1990s, IORVs may be coalescing into a new global SORV. Many global environmental laws and regulations are emerging to go along with the increasing global consciousness that is now taking form throughout the world (John McCormick, 1990). Some feel that we may be at a period in human social thought where leading thinkers from all cultures will join to address the ethics of the environment and development as one unified subject and in a global perspective (Engel, 1990).

The Role of Educators

Educators play a key role in developing IORVs and SORVs. We are the "change agents" that increase the knowledge and change the attitudes in the individuals with whom we work. Those involved in informal adult education work with current resource managers and marine resource users. We can help them understand global issues, possible impacts, and potential solutions, and work within existing socio-political systems to solve problems.

Those teaching in classrooms work with the future resource managers and leaders of our global environment. Here is where many IORVs about the global environment will take shape. There is an opportunity to teach about the world in holistic systems terms. It will be important to integrate both the science and socio-economic dimensions of the issue to the students. This may not be easy for those trained in the marine sciences as one observer has noted...

> "it is hard, if not impossible, to engage in a meaningful discussion of global ecology without involving more economic and political theory than most biologists are comfortable with..." (Levine, 1990).

We must think about and address these global ecological issues in new ways. We need to understand the socio-economic-political world in which we live; how science can identify problems, impacts, and possible solutions; how individual and collective actions ultimately determine the outcome; and then convey these concepts and knowledge to the students and adults that we work with. The challenge is in developing integrated, holistic approaches that can help the student and public better understand that social and natural scientific knowledge is an important part of our world and not a subject reserved for the research laboratories, academics, and politicians.

Development of a Global Environmental Ethic

Education and development of a global environmental ethic appear to be the keys to resolving these problems that face us and future generations. This theme has been echoed in many places. In the mid-1980s, the World Commission on the Environment and Development pointed out that

> "...individuals in the real world will be persuaded or made to act in the common interest through education... education should provide comprehensive knowledge, encompassing and cutting across the social and natural sciences and the humanities, thus providing insights on the interaction between natural and human resources, between development and environment...
>
> Environmental education should be included in and should run throughout the other disciplines of the formal education curriculum at all levels—to foster a sense of responsibility for the state of the environment and to teach students how to monitor, protect, and improve the environment...Adult education, on-the-job training, television, and other less formal methods must be used to reach out to as wide a group of individuals as possible, as environmental issues and knowledge systems now change radically in the space of a lifetime."(*Our Common Future*, 1987).

Ecologists such as Garrett Hardin suggest that we develop a healthy skepticism toward economists, ecologists, and politicians. Hardin points out that we need to focus on planet Earth and develop a systems interdisciplinary approach and attitude to the world in which we live (Hardin, 1985).

Ornstein and Ehrlich suggest that our biological evolutionary path has not been able to keep pace with today's technological changes and that we need to develop a new way of thinking. In the past, humankind has "filtered out" of our thinking the complex problems that are now facing us on the global scale. They suggest that we begin to "filter in" the imperceptible but dangerous trends that now characterize the human environment, and use a variety of sensors that are available to us to discover what is occurring to planet Earth. Like a pilot flying blind through fog, Ornstein and Ehrlich argue that we need to trust what the scientific instruments are telling us. They state we can no longer be ethnocentric in our outlook, but must look at alternative senarios and approaches in dealing with these global change issues. They then contend that : "...everyone needs to incorporate into their thought processes the findings of a diversity of scientific disciplines that make clear that other people and other societies have their own sets of limited truths and needs, not necessarily any 'better' or 'worse' than our own..." (Ornstein & Ehrlich, 1989.)

Callicott also argues that develoment of a global environmental ethic and responsibility for making this happen rests within the educational community. He contends that:

> "...an ethic articulated or advocated by a single creative individual (is) ineffectual unless it becomes generally distributed in the population...(and)...this task is one of environmental education and it falls squarely on the shoulders of educators... " (Callicott, 1989).

A Global Land Ethic

Both formal and informal educators need to develop long-term, pro-active environmental programs that are holistic, interdisciplinary, and integrated with one another. We need to remember the simple message that Aldo Leopold so eloquently voiced in his classic, *Sand County Almanac* over 40 years ago...

> "Mankind needs to develop a land ethic that recognizes the interrelationship of our land, water, and air resources. This ethic changes the role of man from conqueror of the land-community to plain member and citizen of it..." (Leopold, 1949).

Leopold's advice for a land ethic is now needed on a global scale. To develop an ethic of conserving, managing, and utilizing our natural resources as a way of life, we must live an ethic that considers the long-term, as well as the short-term, the biologic as well as the economic, and we must put this ethic into action. Leopold's land ethic stressed "conviction of individual responsibility for the health of the land." He stated that in order to live in harmony with the environment, we must develop an individual and community responsibility to ensure its continued health. Today, an increasing number of people are incorporating this ethic into their daily lives, and using it to influence decisions that have local, national, and international impacts.

We need to instill such a global ethic in the students and adults that we work and come into contact with. Setting an example in our classrooms and personal lives, teaching about "informed actions" and providing practical knowledge that can be put to local use are the keys. There are many written materials that provide this information. One active educator who has written such a book has noted the following:

> "I have witnessed how environmental issues catalyze people. The environment arouses elemental feelings about the future of life on the planet...It is time to move beyond just protecting ourselves from pollution with individual solutions like buying bottled water and organic produce; we must go to the source of the problem and start there...(individual) examples serves as beacons to enlighten us, and models to prod and encourage us to 'go and do likewise.'
>
> Knowledge gives reason to act; and action, in the face of something inevitable and frightening, is empowering. Action gives hope; hope supports action...More people are prepared to think globally because of the perversity of pollution. Now is the time to 'act locally...'"(Hynes, 1990)

Although it appears that the global change issues are serious and environmental crisis lies ahead in the years to come, it also is a time that is ripe with opportunity for positive social change. Perhaps we can view this crisis as the Chinese do. The Chinese symbol for crisis consists of two characters: one means *danger,* and the other means *opportunity.* The scientific community has articulated the *danger* of global change and alarms are sounding throughout the world. There also appears to be an *opportunity* for classroom and informal adult educators on these issues that cut across economic, social, political, geographic, and environmental boundaries. Educational programs and activities are needed that are interdisciplinary, coordinated, international in scope, and call for governmental action and local responsibility. The slogan "think globally, act locally" should be taken to heart, and become part of our daily lifestyle, for individual actions and choices that involve an understanding of the global environment do become the building blocks for governmental actions. The danger and the opportunity have been identified. The question is whether or not we are ready to accept the challenge.

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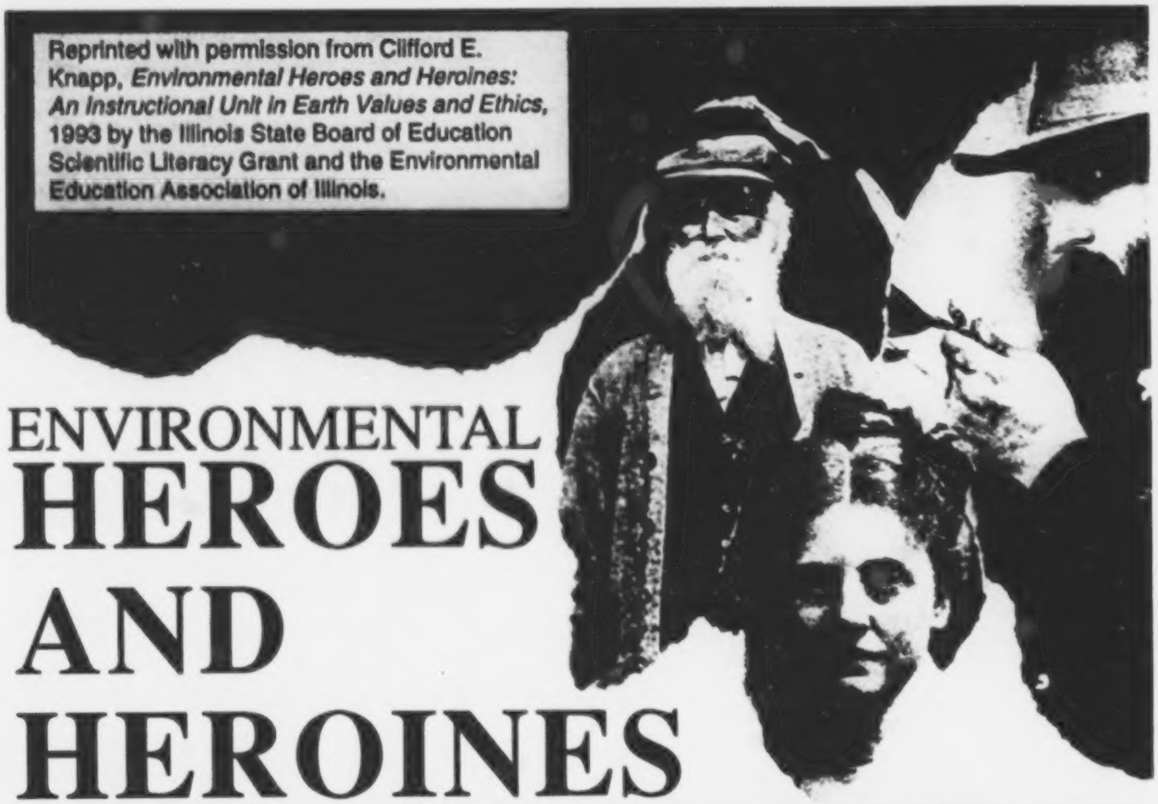

ENVIRONMENTAL HEROES AND HEROINES

An Instructional Unit in Earth Values and Ethics

by Clifford E. Knapp

Introduction

The purpose of this instructional unit is to encourage teachers to involve their students in the study of the values and actions of environmental heroes and heroines in order to help them develop their own earth ethic.

Our society selects heroes and heroines from many professions and all walks of life. These admirable people come from sports, film, television, politics, literature, religion or anywhere else we can find them. With increasing problems, such as environmental pollution, loss of plant and animal species, and other habitat destruction, some people are very concerned about the ability of our planet to support life as we know it. These concerned citizens, often called environmentalists, look to role models in fields such as science, technology, ecology, anthropology, literature or government for guidance and inspiration. Young people, especially, can benefit from learning more about the leaders who make a difference attempting to create a better world through environmental action. By modelling certain behaviors of others whom we admire and respect, we can change how we impact the ecology of the planet.

Let's define an "environmental hero and heroine" and examine how our lives and the lives of our students can be enriched by knowing more about them.

WHAT IS A HERO AND HEROINE?

Joseph Campbell, in his book, *The Power of Myth*, defines a hero as "... someone who has given his or her life to something bigger than oneself."

Webster's New Twentieth Century Unabridged Dictionary lists five meanings of the term:

1. In mythology and legend, a man of great strength and courage, favored by the gods and in part descended from them;
2. Any man admired for his courage, nobility or exploits, especially in war;
3. Any person admired for his qualities or achievements and regarded as an ideal or model;
4. The central male character in a novel, play, poem, etc. with whom the reader or audience is supposed to sympathize;
5. The central figure in any important event or period, honored for outstanding qualities.

A heroine is a female hero, although Campbell includes women in his definition. Which definition has more meaning for you when applied to the ecological health of the planet?

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DECISION-MAKING UNDER SCIENTIFIC UNCERTAINTY

Simply stated, environmental heroes and heroines are persons who are admired and respected for their qualities and achievements in improving and preserving the ecology of earth's natural systems. Heroes and heroines emerge from various fields because they have devoted their energies to changing society's ways of looking at nature.

For example, **John Muir** and **Anna Botsford Comstock** were naturalists who wrote about their adventures in the natural world. **Theodore Roosevelt** and **Petra Kelly** were political leaders who promoted ecological awareness. **Rachel Carson** and **Aldo Leopold** were scientists who wrote and spoke out about environmental problems that concerned them. And **Joseph Wood Krutch** and **Sally Carrighar** were writers who appreciated and interpreted nature though literature.

DO HEROES AND HEROINES HAVE TO BE WORLD FAMOUS PEOPLE?

Heroes and heroines can be identified by their actions in the community or local region, too. They don't have to achieve national or international acclaim. The people who initiate a community recycling program, or organize a campaign to save a threatened wood lot, or write letters to the editor of the newspaper about an environmental concern can also be considered heroes and heroines. We can define the scope of influence for our heroes and heroines because every individual action makes a difference on a world scale.

DO I HAVE TO ADMIRE EVERYTHING ABOUT A PERSON TO CONSIDER HIM OR HER A HERO OR HEROINE?

The answer to this question depends on how you view the terms hero and heroine. If you can accept the idea that no other person shares identical values in every area of your life, you can select only those values that you admire. That means you can value what some people do to protect wildlife, but not value the way they seem to disregard endangered plants. Very few heroes and heroines believe in everything you do or behave in ways that you totally approve of. Values that are not like yours aren't necessarily wrong; they are sometimes simply different. This means, too, that we can select a variety of heroes and heroines as models and others can respect our different choices.

HOW MANY ENVIRONMENTAL HEROES AND HEROINES CAN I HAVE AT ONE TIME?

Why put a limit on the number of people you admire and respect? Environmental concern spans a wide range of problems and issues. The more heroes and heroines we can discover, the more we can expand our value choices and possible ways of taking action to help preserve the earth. This instructional unit is designed to raise the awareness and knowledge levels of students. By examining the underlying values held by the people whom we admire, we can help students develop and refine their environmental ethics. ◆

LESSON 1: WHAT DID THEY BELIVE AND DO?

INVESTIGATING HEROES AND HEROINES

OBJECTIVES

1. To do research on one person who the culture has already selected as an environmental hero or heroine and to list three important biographical facts about him or her.
2. To list at least three important values that this person holds (held) about the environment and its protection and/or improvement.
3. To list at least one action this person has taken to protect and/or improve the earth.

METHOD

Students are to do library research to discover some important information about a person who has been recognized for making contributions to the environment.

BACKGROUND

Environmental heroes and heroines are chosen, in part, because they hold certain values in common with those who select them. Different criteria can be applied in the selection process. Heroes and heroines can be selected with consideration for their gender, race, the amount and quality of their published writings, their visibility in films, videos, cartoons, or recordings, their field or profession within which they worked, the span of time considered, the geographical scope of their influence (local, regional national, international), and other factors.

Several individuals, organizations, businesses, and publications have already honored environmental heroes and heroines. Here are some of them:

● Eddie Bauer, Inc., a Washington-based retail chain, has created the "Heroes for the Earth" program. In 1991 they honored six people who were each awarded $10,000 in the name of the environmental cause they assisted. Each person was recognized for their commitment and lifetime dedication or one-time contribution to the natural world. The 1991 awardees were:

Dr. Birute Galdikas, administrator of an organization devoted to preserving orangutans;

Dale Harris, a leader in a campaign to preserve Montana wilderness;

John Hays, founder of an organization to preserve open space and wildlife habitat and establish a trail system in Washington's Methow Valley;

Cathy Sneed Marcum, director of a San Francisco green house project to organically grow vegetables;

Paul Petzoldt, adventure educator and wilderness advocate who promoted minimum impact camping; and

Michael Werikhe, promoter for preservation of rhinoceroses in Kenya and around the world.

For further information about the program and other awardees, in 1992 and beyond, contact Eddie Bauer: Heroes For The Earth, 14850 NE 36th ST., Redmond, WA 98052, (206) 882-6100.

● *The Mother Earth News*, a bimonthly publication advocating alternative energy and lifestyles, ecology, working with nature, and doing more with less, selected 14 members to their "Environmental Hall of Fame", representing one for each of the years of publication from 1970 - 1984. These recipients, in order of selection, were:

John James Audubon
Henry David Thoreau
John Muir
Theodore Roosevelt
Rachel Carson
David Ross Brower
Jerome Irving Rodale
Aldo Leopold
Jacques-Yves Cousteau
Barbara Ward (Jackson)
Sir Albert Howard
Rene Jules Dubos
Anwar Fazal
Richard St. Barbe Baker

Students may wish to do further research in the library to find out about the other recipients from 1984 to the present. For further information, contact: *The Mother Earth News* (Sussex Publishers, Inc.)., 24 East 23rd St., New York, NY 10010, (212) 260-7210.

● **Douglas Wood**, author, song writer, performer, and environmental educator wrote a song titled, "The Big Trees Are Down." The lyrics celebrate five people who he considered to be environmental heroes and heroines. They were:

Rachel Carson
Aldo Leopold
John Muir
Sigurd Olson
Henry David Thoreau

For information about the audio tape, "Earthsongs," on which the song is recorded, contact: Douglas Wood, EARTH SONG, 104 4th St., Sartell Minnesota, 56377.

● The publisher, Twenty-First Century Books, selected twelve environmental heroes and heroines for their new "Earth Keepers" book series for children in grades 3-7. Those people who joined the fight for a better earth are:

David Brower
Rachel Carson
George Washington Carver
Jacques Cousteau
Marjory Stoneman Douglas
Jane Goodall
Chico Mendes
Margaret Murie
John Muir
Gaylord Nelson
Theodore Roosevelt
Henry David Thoreau

For further information contact: Henry Holt Distribution Center, 4375 West 1980 South, Salt Lake City, Utah, 80104, (800) 488-5233/ (801) 972-2221 or the New York Office (212) 886- 9383.

● In their book, *Great Lives: Nature and the Environment*, Doris and Harold Faber (New York: Charles Scribner's Sons, 1991) selected 26 heroes and heroines:

Louis Agassiz
Roy Chapman Andrews
John James Audubon
Liberty Hyde Bailey
John and William Bartram
Hugh Hammond Bennett
Luther Burbank
John Burroughs
Rachel Carson
George Washington Carver
Alexander von Humboldt
Aldo Leopold
Carl Linnaeus
John Muir
Frederick Law Olmsted
Gifford Pinchot
John Wesley Powell
J. I. Rodale
Theodore Roosevelt
Henry David Thoreau
Jacques Cousteau
Charles Darwin
Jean Henri Fabre
Alfred Russel Wallace
Gilbert White

The book contains four pages of further reading dealing with each of these people's lives.

● A new social studies series: *Creative Lives Series* about explorers, philosophers, inventors and others, presents multidisciplinary units to facilitate self-directed learning and critical/creative thinking. From : Zepher Press, 3316 N. Chapel Ave., Box 13448 - M, Tucson, AZ 85732-3448 (602) 322-5090. Includes **Rachel Carson, George Washington Carver, Jacques Cousteau,** and others.

MATERIALS

Reference books and articles on the selected heroes and heroines and a video about the life of one environmental hero or heroine.

PROCEDURE

If possible, obtain a video on the life of an environmental hero or heroine so all students can view it and learn about the same person. Use this video to illustrate how to identify the significant biographical facts and environmental values that made this person a hero or heroine.

You might start with a discussion that asks students:

How was this person's life like yours? (list on board)
How was it different? (list)
What values did this person develop because of his/her life experience? (list)
Of the values listed, which three do you think brought them the most fame? Why?
Now, can we pick the three life experiences (biographical facts) which helped these values develop?

If there is disagreement about what is "most important", discuss this and the reasons why we each value different things as important. Refer to the discussion of these concepts in the Introduction.

Some examples of videos you might use:

"The Wilderness World of Sigurd F. Olson", distributed by NorthWord, Inc., Box 128, Ashland WI 54806 (800) 336-5666 and The Sigurd Olson Environmental Institute, Northland College, Ashland, WI 54806 (715) 682-1223. Describes the life and spirit of **Sigurd Olson**, who spent his career fighting for northwoods wilderness preservation.

"Wild By Law: The American Experience", narrated by David McCollough (aired in January 1992 on public television). Describes the contributions of **Aldo Leopold, Bob Marshall,** and **Howard Zahniser** in preserving wilderness in the United States.

"A Prophet For All Seasons" distributed by NorthWord Press, Inc., Box 1360, Minocqua, WI 54548 (800) 336-5666. Describes the life of **Aldo Leopold** and includes selections from his essays collectively known as "A Sand County Almanac". Includes comments by **David Brower, Rene Dubos,** and **Susan Flader**.

After the students have examined the life of the same hero or heroine, challenge them to individually select a person to investigate. They may want to read about several people before deciding.

EXTENSIONS

1. Do more research. Find additional heroes and heroines, who in your opinion, deserve to be listed (see page 17). NOTE: To locate more heroines, the following publications are helpful:

Anderson, L. (Ed.) *Sisters of the Earth: Women's Prose and Poetry About Nature*. New York: Vintage Books, A Division of Random House, Inc., 1991.

Camping Magazine, Special issue on "Women in Camping", Vol. 59, No. 4, (February, 1987).

Healing The Wounds: The Promise of Ecofeminism, edited by Judith Plant, Santa Cruz, CA: New Society Publishers (1989).

LaBastille, Anne, *Women and Wilderness: Women in Wilderness Professions and Lifestyles*. San Francisco: Sierra Club Books, 1980.

Nature Study: A Journal of Environmental Education and Interpretation. Special issue on "Women and the Environment", Vol. 42, Nos. 1 & 2 (October, 1988).

2. Divide the class into "media watch" groups. Have each group select certain media to "watch" for one week and to record the names of people highlighted because of an environmental issue. Monitor CNN, public television, local radio stations, major TV networks, inventory local video stores for films, and local and national newspapers.

At the end of the week, collect this information and look for the following: frequency of someone highlighted, related issues, men compared to women, geographical locations — i.e. are there any patterns based on the criteria discussed in the Background section of this activity? Are there any names from this survey that should be added to the master list the class has composed? Have students predict which "seldom heard" names (today) they think will become heroes and heroines? Why? What could make this happen?

3. Explore how the times during which selected heroes and heroines lived might have impacted their values. In other words, how were they (or how might they have been) affected by the other things going on in the region, state, country or world? Consider how these events encouraged or limited their achievements?

4. Research the role models who impacted the selected heroes and heroines. Create an environmental values "family tree" showing the connection that each generation of heroes and heroines had to the next. Consider yourself in the family tree and imagine who will follow you.

5. Write a play, story, poem, or song about the environmental heroes or heroines you have identified. Explore ways to share these stories with other students and the community, i.e. "take your show on the road"; try to get the stories and poems published in the local paper; ask the local radio station to play your song?

6. Analyze the names of the heroes and heroines which appeared on the different lists in the Background section or in other collections that you locate to identify those who appeared on all or most of them. Discuss why some people appear more often than others?

EVALUATION

Make a chart which contains the headings: name of the hero or heroine, biographical facts, and environmental values. Compile these into a book to be shared by all of the students. ◆

LESSON 2: WHAT DID THEY SAY?

QUOTATIONS ABOUT HEROES AND HEROINES

OBJECTIVES

1. To think about what others have said or written about heroes and heroines in general.
2. To write an original quotation about environmental heroes and heroines.

METHOD

Students read some quotations and consider their meanings by answering questions in preparation for writing their own original quotations.

BACKGROUND

Quotations from the lips and pens of famous people have been collected and read for hundreds of years. They captivate people because they clearly express ideas that we might have had in ways that we haven't thought about before. In this lesson, students read quotations about heroes and heroines and then create their own original ones about environmental heroes or heroines.

QUOTATIONS AND QUESTIONS

1. "The Hero can be Poet, Prophet, King, Priest or what you will, according to the kind of world he finds himself born into." -- Thomas Carlyle, *The Hero As Poet*

Can everyone be considered to be an environmental hero and heroine at various times in their lives? Have you ever been one?

2. "A hero is someone who has given his or her life to something bigger than oneself." -- Joseph Campbell, *The Power of Myth*

What are some environmental problems that could be considered to be "bigger than oneself"?

3. "Heroes, then are not only people who grow and change and take journeys but also ones who help transform the Kingdom." --Carol Pearson, *The Hero Within: Six Archetypes We Live By*

What could you do to "transform the Kingdom" by improving the environment?

4. "The moral objective (of heroism) is that of saving a people, or saving a person, or supporting an idea. The hero sacrifices himself for something — that's the morality of it." -- Joseph Campbell, *The Power of Myth*

What environmental problem are you willing to make sacrifices for to help make the planet a better place?

5. "The child makes such identifications (with heroes) all on his own, and the inner and outer struggles of the hero imprint morality on him." -- Bruno Bettleheim, *The Uses of Enchantment*

Do you know any people who you admire and respect for something they have done to help protect the environment? Explain.

6. "... The search for models, and desire to learn from the experiences of others have always been part of the attraction of biography for readers . . . " -- E. Segel, "In Biography for Young Readers, Nothing is Impossible", *The Lion and the Unicorn*

Have you ever read something about the life of a person who has done something for the environment? What did that person do?

7. "The most dangerous man in the world is the contemplative who is guided by nobody. He trusts his own visions. He obeys the attraction of an inner voice, but will not listen to other men." -- Thomas Merton, *New Seeds of Contemplation*

When is it a good idea to listen to others for guidance and when is it not?

8. "We can't all be heroes because somebody has to sit on the curb and clap as they go by." -- Will Rogers

Have you ever told someone or written them a letter to express how much you admired them for something they did for the environment?

9. "Even when walking in a party of no more than three, I can always be certain of learning from those I am with. There will be good qualities that I can select for imitation and bad ones that will teach me what requires correction in myself." -- Confucius

What personal behaviors related to the environment could you correct in the future?

10. "Heroism for this age requires us to take our journeys, to find the treasure of our true selves, and to share that treasure with the community as a whole — through doing and being fully who we are. To the degree that we do so, our Kingdoms are transformed." -- Carol Pearson, *The Hero Within: Six Archetypes We Live By*

Can you share something that you did to improve the planet? Explain.

11. "It's a great temptation to mythologize our heroes and heroines, but we do so at the risk of losing touch with the fullness of who they were, and of creating an unwarranted distance between their lives and our own — with our own too apparent foibles and flaws." -- Dan Conrad, "Reflections on Living with Respect", *The Journal of Experiential Education* (August, 1992)

Do you agree that we often have some things in common with our environmental heroes and heroines?

12. "... There are two types of deed. One is the physical deed, in which the hero performs a courageous act in battle or saves a life. The other is the spiritual deed, in which the hero learns to experience the supernormal range of human spiritual life and then comes back with a message." -- Joseph Campbell, *The Power of Myth*

Can you name one physical deed and one spiritual deed or message you could give to others about the environment?

13. "All around the world, the efforts to stop the destruction of the environment have come mainly from people who recognize the damage being done in that part of the world in which they themselves have 'dominion'." -- Al Gore, *Earth in the Balance*

Can you name one person in your community who has done something to improve the local environment? Explain.

14. "... Men and women who care must be politically empowered to demand and help effect remedies to ecological problems wherever they live." -- Al Gore, *Earth in the Balance*

How can you encourage our governmental officials to do something to improve the environment?

15. "If a child is to keep alive his (or her) inborn sense of wonder without any such gift from the fairies, he (or she) needs the companionship of at least one adult who can share it, rediscovering with him (or her) the joy, excitement and mystery of the world we live in." -- Rachel Carson, *The Sense of Wonder*

What adult has helped you to discover the joy, excitement and mystery of the world you live in? Would you consider this person a hero or heroine? Explain.

MATERIALS

Lists of quotations and questions, blank paper, and something to write with.

PROCEDURE

Ask the students to read the quotations and respond to the corresponding question. Discuss the responses in small or large groups. Then ask the students to create their own quotations about environmental heroes and heroines and share them with others.

EXTENSIONS

1. Find more written or spoken quotations that relate to environmental heroes and heroines and share them with others.
2. Compile the student-written quotations about the environment and produce a book to share with the community.
3. From the investigations done in Lesson 1, choose a quote by a selected hero or heroine and make a poster including the quote and an illustration created with paint, chalk, a collage of pictures cut from magazines, etc.

EVALUATION

...Select an environmental hero or heroine and write an original quotation saying something that you imagine that person would say or that you would like them to say. ❖

LESSON 3: WHAT DO I BELIEVE AND WHAT CAN I DO?

WHAT ENVIRONMENTAL VALUES DO I HOLD?

OBJECTIVES

1. To examine various environmental values positions and decide which ones are personally more important.
2. To identify people who have developed and promoted some of these environmental values.

METHOD

Students respond to and discuss several questions which encourage the expression of their environmental values and learn about people who share some of these views.

BACKGROUND

All environmentalists do not hold the same values about human and non-human nature. There is a wide range of beliefs among those who are working to "save" the earth and its inhabitants. In fact, some environmentalists are even critical of others because they disagree with their goals and/or methods. Each one of the major viewpoints listed in the lesson are more complex than can be stated briefly and therefore, selected references are provided for further reading. (See especially, Joseph R. Des Jardins' *Environmental Ethics*, Belmont, CA: Wadsworth Publishing Company, 1993.)

The positions are:

1. Animal Welfare
2. Reverence For Life
3. The Land Ethic
4. Deep Ecology
5. Social Ecology and Ecofeminism
6. Radical Ecoactivism
7. Wise Use and Management
8. Indigenous or "First" Peoples

1. All "Animal Welfare" positions are not alike, but generally they honor individual animals and value them for various reasons.. Most animal welfare advocates are critical of raising animals for food and furs, keeping them in zoos, having some pets, using them for scientific research, and hunting and trapping them for sport or sale. Many of these people would therefore suggest that we become vegetarians for moral reasons, however they usually do not extend moral rights to all living things such as bacteria, viruses, ticks and mosquitoes. For further reading see: Peter Singer's *Animal Liberation* (2nd) Edition New York: New York Review of Books, 1990; and Tom Regan's *The Case for Animal Rights*, Berkeley, CA: University of California Press, 1988.

2. The person who developed and promoted the "Reverence for Life" position was **Albert Schweitzer**. He described this view as an attitude of awe and wonder towards all of nature. He believed that it was good to preserve and promote life and evil to destroy and injure life. He believed that all living things had inherent worth, apart from how humans benefited from them. Schweitzer wouldn't kill mosquitoes or use DDT because of its affects on all life, although he did kill his own pelican when he learned that its injuries were untreatable. He didn't believe that some forms of life were better than others. The "Reverence for Life" value position did not answer all the questions about how a person should behave, but it provided a general guideline for living the good life.

For further reading see: James Brabazon's *Albert Schweitzer: A Biography*, New York: Putnam, 1975; Albert Schweitzer's *Out of My Life and Thought*, New York: The New American Library, 1953; and Ann Cottrell Free's *Animals, Nature and Albert Schweitzer* (1982) — available from each of the publishers, the Albert Schweitzer Fellowship, The Animal Welfare Institute, The Albert Schweitzer Center or the Humane Society of the United States.

3. "The Land Ethic" value position was originally developed by **Aldo Leopold**. This view depends upon an understanding of the science of ecology and the relationships among the parts of ecosystems. It also incorporates the belief that human beings are just one part of a larger earth community of plants, animals, soils, waters, collectively called "the land." Living things are viewed from the perspective of populations rather than individual animals and plants. Leopold wrote about the land as being a living thing and about maintaining it in good health. He believed that responsible actions would result if a person loved and respected the land. For further reading, see: Aldo Leopold's *A Sand County Almanac*, New York: Oxford University Press, 1949 and Curt Meine's *Aldo Leopold: His Life and Work*, Madison WI: The University of Wisconsin Press, 1987.

4. The "Deep Ecology" value position deals with the deep, underlying causes of pollution and resource depletion. **Arne Naess** and other proponents of this approach believe that society must make radical changes and that individuals must adopt a new world view or philosophy. The deep ecology movement is based on eight principles, including ideas such as the inherent value of non-human life forms, the decrease of human population, and the need for policy change in the use of resources. The science of ecology is valued, but not as the only set of guiding concepts.

For further reading see: Bill Devall's *Simple in Means, Rich in Ends*, Layton, Utah: Gibbs Smith Publishing, 1988 and Bill Devall and George Sessions' *Deep Ecology: Living as if Nature Mattered*, Salt Lake City: Peregrine Smith Books, 1985.

5. Although "Social Ecology and Ecofeminism" differ to some degree, they are alike in some important ways. **Murray Bookchin** has written about social ecology; a number of authors such as **Karen Warren, Susan Griffin, Carolyn Merchant, Mary Daly** and **Ynestra King** have contributed to the growing body of ecofeminist literature. Both value positions view ecological destruction as related to social and political attitudes such as control and dominance. They believe that the destruction of nature results from oppressive patterns and social hierarchies such as men over women, the white race over people of color, and moneyed and educated classes over the poor and illiterate. Ecofeminists believe that the oppression of women by men is the most destructive form of social dominance and that this has a direct relationship to the attempted control of nature.

For further reading see: Murray Bookchin's *The Philosophy of Social Ecology*, Montreal: Black Rose Books, 1990; the American Philosophical Association's *Newsletter on Feminism and Philosophy 90*, No. 3 (Fall, 1991); and *Healing the Wounds: The Promise of Ecofeminism*, edited by Judith Plant, Santa Cruz, CA: New Society Publishers (1989).

6. The "Radical Ecoactivism" value position could be considered to be an extreme form of some "Deep Ecology" and "Animal Welfare" views. It includes both legal and illegal ways of dealing with polluters and "destroyers:" of nature. Organizations such as Greenpeace usually practice legal acts of civil disobedience such as sailing between whalers and whales. Organizations such as Earth First led by **David Foreman** and advocates of "monkey wrenching" (destroying or disabling environmentally destructive technology such as bulldozers, logging equipment, or fishing gear) such as **Edward Abbey**, sometimes take illegal actions to stop what they consider to be threats to the survival of the earth and its ecological systems.

For further reading see: Dave Foreman's *Confessions of an Eco-Warrior*, New York: Harmony Books, 1991 and Edward Abbey's *The Monkey Wrench Gang*, Salt Lake City, Utah: Dream Garden Press, 1985.

7. The "Wise Use and Management" position views nature as primarily useful to humans. Plants, animals, and land are sometimes valued if their existence does not conflict with human needs. Nature is protected in places, such as parks and forests, but this is often done because of the potential use of humans rather than because the plants, animals, or habitats deserve protection for their own sakes. Animals are often defined in terms of their human impact, such as pests, vermin, and game. Animals are mainly viewed from the perspective of populations rather than individuals. Populations are monitored and controlled through quotas or bag limits placed on hunters, trappers, and fishers. Habitats are managed for their production of specific game animals rather than for animals which have little direct human use. Humans are viewed as separate from other animals and therefore, responsible as stewards of nature. Some leading proponents of management approaches are Frederick Law Olmsted, Gifford Pinchot and Theodore Roosevelt. For further reading see Douglas Strong's *The Conservationists*, Menlo Park CA: Addison-Wesley Publishing Company, 1971.

8. 'Indigenous or 'First' Peoples", such as Native Americans in what eventually became the United States, view nature as sacred. They believe that all forms of living and non-living things are connected and therefore, humans belong to the same society as other animals, rocks, rivers, and plants. All of nature, including the planet earth, deserves respect and gratitude in the form of prayer, rituals and ceremonies. Land exists to support life and is not to be misused or restricted through ownership by individuals. Humans are seen to have a great deal of responsibility for maintaining the balance and harmony that exists on earth. For further reading see: Suzuki & Knudtson's *Wisdom of the Elders: Honoring Sacred Native Visions of Nature*, New York: Bantam Books, 1992; Chief Dan George & Hernschall's *My Spirit Soars*, Blaine, WA: Hancock House Publishers, 1989; and Susan Jeffers' *Brother Eagle, Sister Sky: A Message from Chief Seattle*, New York: Dial Books, 1991.

MATERIALS

A sheet of environmental values questions and students' notes on their answers.

PROCEDURE

The teacher can provide a brief description of the eight types of environmental value positions described in the background section of this lesson. At this point, the names of those who are associated with each position are not important for students to memorize. Students should be given the following list of questions and asked to think and write on each one.

Then, each question can be discussed in small groups or as a whole class. The purpose of the discussions is not to have the students criticize others' responses or to try to change their positions, but to listen carefully to the different responses and to try to understand the stated reasons for holding these views.

Following this exercise, have the students identify different people who hold one or more of these positions.

ENVIRONMENTAL VALUES QUESTIONS

Directions: Read each question and write your answer. Think about your reasons for responding the way that you did to each question.

1. Do you think it is right to raise animals for their fur and leather and then make coats, gloves, shoes and other wearing apparel? Do you wear anything made from animals? If so, what? Would it make any difference if the wearing apparel were obtained from a wild animal that was shot or trapped for that purpose?

2. Have you ever thought about being a vegetarian? What are the disadvantages and advantages of become one? If eating meat is not a good thing, why is eating plants any different?

3. Do you have a pet? Why might some environmentalists think that you shouldn't have one? Are some pets right to keep and others not right?

4. Have you enjoyed going to the zoo or circus? Have you ever thought about how the animals were treated in each place? Do you agree with some environmentalists that zoos and circuses mistreat some animals?

5. Do you agree with Albert Schweitzer that it's wrong to kill a mosquito even if it is biting you? Are some animals considered pests and others useful to humans? Is it right to kill some animals and protect others because of how they harm or help humans?

6. Some kinds of living things such as bacteria and viruses cause human diseases. Should these harmful organisms be eliminated from the earth if it were possible?

7. Is it right to use some pesticides on crops to get higher yields, even though they kill some insects and other organisms and the pesticides could get into the ground water that humans depend upon for drinking?

8. Is it right to shoot or trap some animals if their populations in the area are large enough to assure that they will reproduce young next year?

9. Is it a good idea for government to control when animals are hunted or trapped and how many should be killed by each hunter or trapper? How many should be killed by each hunter or trapper? Is it ever right to kill females and young from a certain animal species if there are too many of them in that habitat?

10. What conveniences or luxuries would you be willing to give up to make less impact on natural systems? Would it matter if you were the only one giving them up?

11. Do you think it is right to try to control nature by using different forms of technology such as irrigating dry land, seeding clouds to produce rain, or making fresh water from salt water? Does it matter how much these actions add to pollution or the cost of the final product?

12. Is it ever right to break a law in taking action to protect the environment? Give examples to support your position?

13. How would we treat the earth if we really believed that all living and nonliving beings had spirits and were to be honored? What specific laws or policies would be created? What would you do differently?

14. Should a specific animal or plant be preserved even if it proved to be of no value for human survival? Explain.

15. Which values position(s) do you believe the government in your community most closely represents. Give specific examples of why you believe as you do?

EXTENSIONS

1. Read about some of the people discussed in this lesson who you admire for their beliefs and/or actions.

2. Make up your own list of environmental values questions and share them with others in the class.

3. Make up a questionnaire on a specific environmental problem or issue and take a survey in the community. Classify the responses according to the eight positions discussed in this lesson. What patterns emerge? Why would one position be more dominant than others? Did you discover some people who hold similar values to yours? Did you discover any patterns to the responses according to gender, age, ethnic origin, or anything else? Did you find any new heroes or heroines?

4. Using the chart created in the evaluation section of Lesson 1, classify each hero or heroine according to the position their values or actions reflect.

Note: In some cases more than one position may be reflected. Is there any pattern to the combinations?

5. Which values position(s) do you think the elders in your family hold? Talk to them and try to determine how their views developed and how they are reflected in their behaviors, i.e. who they vote for; what they do for recreation; what they eat; how they manage the material possessions that they have. How have their values positions affected you?

EVALUATION

1. Write a paragraph describing the environmental value position which comes closest to your philosophy? Give examples from your life.

2. Who might become your hero and heroine from this value position? State three qualities or actions of the person that you admire. ◆

ENVIRONMENTAL HEROES AND HEROINES

People to investigate for their views on caring for the earth.

1. Abbey, Edward
2. Adler, Margot
3. Agassiz, Jean Louis
4. Andrews, Roy Chapman
5. Audubon, John James
6. Austin, Mary
7. Bailey, Liberty Hyde
8. Baker, Richard St. Barbe
9. Bartram, John and William
10. Baylor, Byrd
11. Beard, Daniel B.
12. Bennett, Hugh Hammond
13. Berg, Peter
14. Bigelow, Maurice A.
15. Blanchan, Neltje
16. Bookchin, Murray
17. Boyden, Arthur
18. Brower, David
19. Burbank, Luther
20. Burgess, Thornton
21. Burroughs , John
22. Carrighar, Sally
23. Carson, Rachel
24. Carver, George Washington
25. Cather, Willa
26. Chapman, Frank
27. Commoner, Barry
28. Comstock, Anna Botsford
29. Cousteau, Jacques-Yves
30. Daly, Mary
31. Darling, Jay Norward (Ding)
32. Darwin, Charles
33. de Chardin, Teilhard
34. Deloria, Vine, Jr.
35. Douglas, Marjory Stoneman
36. Dubos, Rene Jules
37. Ehrlich, Paul
38. Eifert, Virginia
39. Eiseley, Loren
40. Elk, Black
41. Emerson, Ralph Waldo
42. Fabre, Jean Henri
43. Fazal, Anwar
44. Foreman, Dave
45. Fuller, Buckminster
46. Fuller, Margaret
47. Galdikas, Birute
48. George, Chief Dan
49. Gibbs, Lois
50. Gnau, "Harrison"
51. Goodall, Jane
52. Gordon, Eva L.
53. Gray, Elizabeth Dodson
54. Griffin, Susan
55. Gyatso, Tenzin
56. Hardin, Garrett
57. Harris, Dale
58. Harris, William T.
59. Hays, John
60. Hodge, Clifton F.
61. Howard, Sir Albert
62. Jackman, Wilbur S.
63. Kelly, Petra
64. King, Thomas Starr
65. King, Ynestra
66. Krutch, Joseph Wood
67. LaBastille, Anne
68. LaChapelle, Dolores
69. Larson, Gary
70. Leopold, Aldo
71. Linnaeus, Carl
72. London, Jack
73. Long, William J.
74. Lopez , Barry
75. Marcum, Cathy Sneed
76. Marsh, George Perkins
77. Marshall, Bob
78. Mason, Bill
79. Mather, Stephen T.
80. McCloskey, Alice
81. McGaa, Ed (Eagle Man)
82. McHarg, Ian
83. Mendes, Chico
84. Merchant, Carolyn
85. Mikulski, Barbara
86. Mills, Enos A.
87. Miner, Jack
88. Momaday, N. Scott
89. Muir, John
90. Murie, Margaret
91. Murie, Olaus
92. Naess, Arne
93. Nash, Roderick
94. Nelson, Gaylord
95. Olmsted, Frederick Law
96. Olson, Sigurd
97. Osborn, Fairfield
98. Palmer, E. Lawrence
99. Payne, Frank O.
100. Petzoldt, Paul
101. Pinchot, Gifford
102. Powell, John Wesley
103. Rich, Louise Dickinson
104. Roberts, Charles G. D.
105. Rodale, Jerome Irving
106. Roosevelt, Franklin D.
107. Roosevelt, Theodore
108. Roszak, Theodore
109. Russell, Helen Ross
110. Schumacher, E. F.
111. Scott, Charles
112. Seattle, Chief
113. Seton, Ernest Thompson
114. Sharp, Dallas Lore
115. Sheldon, Edward A.
116. Snyder, Gary
117. Spencer, John W.
118. Standing Bear, Luther
119. Storm, Hyemeyohsts
120. Straight, H. H.
121. Suzuki, David
122. Teale, Edwin Way
123. Thoreau, Henry David
124. Udall, Stewart
125. Unsoeld, Jolene
126. Van Hise, Charles
127. Vinal, William
128. Vogt, William
129. von Humboldt, Alexander
130. Wallace, Alfred Russel
131. Walton, Izaak
132. Ward(Jackson), Barbara
133. Warren, Karen
134. Watts, May Theilgaard
135. Werikhe, Michael
136. White, Gilbert
137. Whitman, Walt
138. Wilson, Edward O.
139. Wright, Mabel Osgood
140. Zahniser, Howard

Names in bold text have been referred to in this instructional unit.

UNIVERSITY OF FLORIDA

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Enviroshopping Energy Considerations

Florida Energy Extension Service EES-73

Marie S. Hammer and Joan G. Papadi*

Excess trash affects us in many ways even before it becomes trash. There is potential damage to the environment when raw materials are mined, drilled or extracted, and then transported to the factory. Air and water pollution can occur during manufacturing, storage, and transportation of the finished products to the retail store.

Since energy is used in each of these steps, there are environmental consequences. From coal, oil, or gas-fired electrical energy, there are large amounts of harmful atmospheric pollutants. Accidents can occur when transporting fossil-based fuels and this can also degrade the environment.

Most people are aware of the environmental damage possible when disposing of waste by landfill or burning but few people realize that creating a product such as packaging from raw materials causes even more environmental damage than disposing of it. The damage is a direct result of the large amount of energy consumed when manufacturing a product. Additionally, when the solid waste is placed in a landfill, it continues to affect the environment. Landfills that were built before today's strict standards have the potential to contaminate water supplies.

Excess trash also wastes resources. The raw materials we use to make our paper, plastic, and other materials, all need to be conserved for future generations.

Thirty percent of our household waste is packaging. But we can't just eliminate it. Packaging is a necessary part of our marketing and distribution systems. It performs several functions by:

- protecting food from light, heat, oxygen, natural contamination, and tampering. It preserves food and prevents food waste.
- protecting consumer goods from crushing, soiling, or being stolen.
- protecting children from ingesting drugs or hazardous chemicals.
- informing consumers of proper use, storage, features, and warranties.
- making warehousing, transportation, and distribution easier because these items can be handled with large scale mechanical equipment.
- providing convenience to the consumer in ready-to-eat, single serving, disposable and microwavable containers.
- encouraging multi-packs or quantity purchases.
- drawing the eye of the shopper away from the competition through the use of attractive packaging.
- using more shelf space and larger packages to attract shoppers.

Packaging varies widely in its efficient use of materials. While some packaging is designed for the utmost in efficiency, other packaging is excessive. Unnecessary packaging wastes energy and valuable materials and contributes to the waste disposal problem. Some of the improvements made for convenience sake or to increase shelf life, may produce packages that use more materials, or are more difficult or impossible to reuse or recycle.

The amount of packaging going into the waste stream *can* be reduced significantly. It's up to you. Do your part. BE AN ENVIROSHOPPER! Follow the five "R's" of enviroshopping:

REDUCE the amount of packaging you buy and throw away.

REUSE and

RECYCLE whenever possible.

REJECT packaging that is unsatisfactory, and

RESPOND to producers and retailers to let them know how you feel.

Reduce

We consumers have become hooked on convenience and pay millions of dollars for it. We prefer to buy *sixteen* one-use spray bottles full of ready to use spray cleaner rather than a *single* bottle of concentrate to mix on our own. We do this because we like no muss, no fuss and convenience!

Associate Professor, Extension Home Environment Specialist and Waste Management Assistant. Printed 9/91.

Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.

DECISION-MAKING UNDER SCIENTIFIC UNCERTAINTY

Enviroshoppers are willing to give up some convenience in order to reduce their garbage production. In Florida we throw away over eight pounds of garbage per person every day. This is twice the national average. Although the Florida rate is increased somewhat by the trash from tourists (40 million in 1990), we still need to learn to reduce our garbage by **precycling.** When you precycle, either you choose products and packaging which have less of a negative environmental impact, or you decide to do without and don't buy it at all. If you don't buy products with excessive packaging, you won't have to decide if it can be reused or recycled, and you don't have to dispose of it.

The Summary of National Energy Savings from Packaging Reduction, (Table 1) shows the impact in energy savings of various packaging reduction actions by consumers and industry. Reducing all packaging in general could save the equivalent of *seven million barrels of oil* each year. Imagine seven million barrels of oil going up in smoke, creating air pollution, all to produce packaging that we throw away. Your precycling actions *will* make a difference.

Table 1. Summary of national energy savings from packaging reduction[1].

Packaging Reduction Options	Potential Energy Savings Per Year (Energy Equivalent in Barrels of Oil)
GENERAL	
General packaging reduction	7 million
RETURNABLE CONTAINERS	
Increase in refillable soft drink containers	1 million
Increase in reusable soft drink carriers	265 million
Increase in 3-quart plastic milk jugs	40 thousand
10% increase in reusable corrugated containers	490 thousand
PACKAGE REDESIGN	
Replacement of squat 1/2 pint milk pack with 'Ecopak'	2 thousand
Lightweighting, new processes in soft drink containers	515 thousand
LARGER PACKAGE DESIGN	
Increasing sales of larger size soft drink containers	75 thousand

[1] Source: Love, Peter. "Energy Savings from Solid Waste Management Options." Resources Policy, March 1978, pp. 53-69.

Enviroshoppers compare the convenience of a product to its environmental impact. In some cases you will need the added convenience that only a certain type of packaging can provide. Remember that choosing less is better, from an energy, conservation, and environmental point of view.

Reuse

Present day packaging is a wonder of modern technology. It is often durable, versatile, and attractive. Whenever you can, think of ways to reuse packages. Reuse will save you the money of buying a replacement item, and save the energy, materials, and landfill space, and reduce pollution. Here are some reuse examples.

- Wooden boxes can be covered with fabric, and a cushion added to the top. Pronto you have a new stool to sit on.
- Drawstring mesh citrus bags make good laundry bags. Hang one on the door knob in each child's room. They might use them! (Use only for children old enough to handle the string safely.)
- Frozen and microwavable convenience foods often come with their own dish. Reuse these dishes for making your own convenience meals. When you cook, cook extra or use leftovers to refill the dishes, wrap in freezer wrap or place in a freezer container, and you have your own "instant" meals.
- Plastic bags and wraps can be reused for storing items.
- Packaging materials such as polystyrene, plastic quilting and similar packaging materials can be saved and reused for the same purpose.
- Plastic containers can be reused for food storage, also for scoops and watering devices. Glass jars can help organize nails and tacks and other household and shop items.
- Your local social service agencies, such as schools, child care centers, and senior centers can often use empty containers for projects for their clients. Call them.
- Packaging provides an excellent resource for your creativity. You have paid for it, make use (and reuse) of it!

Recycle

Recycling is an important part of our waste management strategy. In Florida especially we are required by state law to reduce our solid waste through recycling.

Recycling also saves energy. Producing packaging material from recycled stock takes less energy

Table 2. Energy saving potential by recycling.

Material Recycled	Energy Saved by Recycling Material[1]	Equivalent Energy Saved per ton (gallons of gasoline)[2]
Aluminum	95%	1915
Plastics	88%	695
Newsprint	34%	67
Corrugated Paper	24%	51
Glass	25%*	31

[1] Stauffer, R.F. "Energy Savings from Recycling." Resource Recycling, "Vol. VII, No. 7, Jan/Feb 1989, pp. 24-25+.

[2] Roy Johannesen, former Mechanical Engineering Specialist, Energy Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Personal computations, 4/90.

than making it from new raw materials. The "Energy-Saving Potential by Recycling," (Table 2), ranges from 95% to 25% for glass and corrugated paper.

Since aluminum yields the greatest energy savings, if each member of a family of four saved one can each day for a year, they would save the equivalent energy in gasoline to drive a 30 mile per gallon car about 2000 miles. We cannot afford to waste either the aluminum or the energy. It's important for each of us to recycle as much as possible.

What kind of packages can you recycle? Aluminum, glass, steel and tin are recyclable. Some paper and some plastic containers can also be recycled. They all are easier to recycle when they are single material packages, rather than a mixture of two or more in one package.

For recycling to succeed, it depends on you. You have to provide used materials to be collected and reprocessed. But that is only the beginning of your role in recycling. **No material is really recycled until you buy it again after it is made into something new.** It is up to you, as an enviroshopper, to buy recycled materials whenever you can. Look for the recycled symbol on packages you buy.

Reject

Enviroshoppers also reject materials and products that cannot be reduced, reused, or recycled. For example, you can reject packaging that uses more material than necessary. One way to do that is to buy the largest quantity possible in one package. Two quart containers contain more packaging material than one half-gallon container. So much more, that if 70 million American households bought a half-gallon container of milk a week instead of two quarts, they would reduce paper discards by 41.6 million pounds and plastic discards by 5.7 million pounds a year. This would save $145.6 million in packaging and more than 1 trillion Btu (British thermal unit) of energy, enough to heat and cool 7,500 households for an entire year.

You have the most powerful tool in our economy – your wallet. When shoppers stop buying a product, the producers find out why and make changes to comply with their customer's needs. If you buy products and materials that are wasteful, harmful to the environment, or poor quality, you are sending a clear message that you want these to be produced. On the other hand, if you **won't** buy them, you are also sending a message. The producers will listen, either way.

Respond

There will be times, however, when you will not have a choice. A product you want to buy may not be available in a package that is recyclable or reusable. Perhaps the package of your favorite brand has been redesigned to incorporate several types of materials rather than one. Perhaps your grocer doesn't stock concentrated refillable cleaners.

In each of these cases, it is time for the fifth "R" of enviroshopping: RESPOND. Start with your local store manager. Let the manager know you are concerned about the solid waste problem. Ask for refills. Ask for loose produce. Encourage the manager to consider source reduction and recyclability in the products offered for sale.

Contact the manufacturer of products in which the packages are not recyclable, or are excessive. You can request that manufacturers reduce their toxicity of their packaging through changes in design and use of nontoxic inks, for example. You will find the name and address of the company on the package of all consumer goods. Many companies offer a toll-free telephone number. Look for one on the package, or contact your local consumer affairs office or local library to get telephone numbers for major companies. It takes only a small number of letters or phone calls from consumers for manufacturers to consider changes in their products.

Encourage local government officials to initiate or expand a recycling program in your community. Suggest that government regulations be revised to allow for purchase of recycled materials for municipal supplies.

Enviroshopping

You have a tremendous influence in the board rooms of American companies. They listen each time you open your wallet. They will listen when you say "Reduce the amount of packaging you use. Reuse recycled materials. Give us packaging we can recycle." They also know when you reject their product and respond to your demands. As an enviroshopper, consider the environment when you compare the convenience, the cost, and the quality of your purchases. You will feel proud that you've done the right thing for the environment and future generations.

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NINETY WAYS TO MAKE A DIFFERENCE IN THE NINETIES

WHAT YOU CAN DO IN A TYPICAL DAY

Bathroom

1. Take a shower instead of a bath.

2. Turn off the water when brushing your teeth or shaving.

3. Install a water-saving shower head.

4. Put a water dam or a refilled plastic bottle in your toilet tank to use less water per flush.

5. Use cloth napkins and dish towels instead of paper.

6. Use glass dishes and cups and metal silverware instead of plastic or paper.

7. Separate your food waste and other organic materials from the rest of your garbage—recycle and compost.

The Commute to and from Work or School

8. Use public transportation, car pool, ride a bike or walk.

9. Drive a more fuel efficient car, and drive it more efficiently—have your car tuned as needed and keep the engine filters clean.

10. Install the most efficient tire available on the market. This improves fuel economy by 1 to 3 miles per gallon. Make sure your tires are properly inflated.

11. Don't buy air conditioning for your car unless you need it. Buy a light colored car and have your windows tinted; it will need less air conditioning.

12. Observe the posted speed limits.

AT THE WORKPLACE OR SCHOOL

13. Make double-sided photocopies; use reverse side of paper.

14. Use less paper; instead use computer or word processor.

15. Turn off lights in rooms not being used.

16. Recycle your own waste paper internally into message pads and memos, and take waste office paper home to use a scratch pads.

17. Take lunch to work or school in reusable containers.

18. Encourage your company to buy recycled paper for use as stationery and envelopes.

19. Set up a recycling program.

20. Urge the PTA to endorse an environmental curriculum for your school.

21. Supplement what your children are learning about the environment at school with lessons you can teach them at home.

Shopping and Consumerism

22. Don't bank at institutions that fund deforestation. Instead, bank with a small, locally responsible institution.

23. Don't buy dyed toilet or tissue paper. The dyes contribute more toward water pollution.

24. Whenever possible, buy returnable bottles and cans.

25. Bring home groceries in the fewest number of bags possible or bring bags of your own from previous trips to the store and leave bag ties at the store.

26. Buy food and other products wrapped in the least amount of packaging possible.

27. Buy non-aerosol sprays.

28. Shop at farmers' markets or co-ops that support local farms and low-input agriculture. Insist on chemical-free foods.

29. Refuse to buy food that is served in or on polystyrene plastic.

30. If you must buy batteries, buy the nickel-cadmium rechargeable type. Don't toss used batteries in the trash. Save them in a box on a shelf and wait for a toxic garbage pick-up.

31. When purchasing appliances, select ones which are most energy and water efficient.

National Wildlife
EnviroAction

April 1993

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32. Don't buy halon fire extinguishers—halon depletes the ozone layer. Even if you never have a fire, the halons can leak out of the extinguisher and into the air.

S.C. Delaney/U.S. EPA

33. Don't buy tropical wood products. Skip the teak, mahogany, rosewood, ebony, iroko; instead use oak, pine, cherry, birch, or maple.

34. Borrow or rent items you don't use often and maintain and repair the items you own to ensure longer product life.

35. Find alternatives to store bought wrapping paper.

36. Buy a live holiday tree and then plant it. If it dies, recycle by having it ground into mulch.

37. Give gifts that keep on giving—an experience, low-flow shower head, a tree.

Chores—Inside and Out

38. Buy a front loading washing machine—it uses 40% less water than a conventional machine.

39. Use a "solar dryer"—clothes line—or use gas rather than electric dryer.

40. Always use low-phosphate or phosphate-free cleaning products in clothes washers and dishwashers.

41. Use chlorine bleach sparingly, or switch to a non-chlorine bleach like borax.

42. Avoid unnecessary use of toxic household cleaners. Use up your household products entirely before throwing them out.

43. When gardening, plant vegetation that is suited for that particular climate and environment.

44. Adopt a program of integrated pest management to avoid toxic chemicals.

45. Mow your lawn only as it needs it. Set your lawnmower blade high—higher grass retains moisture and needs less water and weeding. Fertilize your lawn and feed the soil, not the plant.

46. Instead of using a gasoline-powered leaf blower, rake.

47. Don't wash off sidewalks with water—sweep.

48. Don't dump leftover toxic chemicals onto the street, where they can get into the sewer.

49. Match the lawn or garden appliance with the task which needs to be accomplished.

Home Care and Energy Conservation

50. Use daylight for lighting whenever possible.

51. Replace fixtures that use two or more low wattage bulbs with one that uses one bulb.

52. Switch to fluorescent light bulbs. They last 10 times longer than incandescent bulbs, produce more light and are three to four times more efficient.

53. Weatherize your house—add insulation to doors, windows, attic floors and ceilings.

54. When building or buying a home, take maximum advantage of the climate, available sunlight and wind patterns.

55. Keep your cooling and heating equipment in top operating condition.

56. Use a clock thermostat for your heating/cooling system.

57. Don't place lamps or television sets near your air conditioning thermostat.

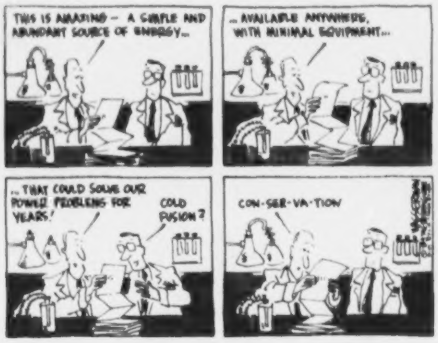
58. Use body heat to keep warm and turn down the thermostat.

59. Keep your fireplace damper tightly closed except when it is in use.

60. Use drapes or thermal curtains to keep heat from escaping through windows.

61. Install your dishwasher away from your refrigerator or freezer.

Feature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COLD FUSION?
CON-SER-VA-TION

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62. If you choose a gas range, choose a unit with an electric ignition.

63. Leave lead-based paint undisturbed if it is in good condition. Do not sand or burn off paint that may contain lead.

64. Test your home for formaldehyde gas; beware of products that may contain it—chipboard, plywood, carpet and upholstery. Test for radon gas.

65. Install plastic storm windows or new "superwindows."

Recreation—Vacation

66. Plan your trips carefully. Choosing the shortest, least congested route will save fuel.

67. Take a train or bus instead of a plane.

68. When camping, choose the right equipment and minimize the impact of your campsite. Wash yourself and your clothes at least 100 feet away from the water.

69. Patronize lodging facilities and restaurants that engage in good environmental practices.

70. Avoid damaging soil with mountain bikes.

71. Properly dispose of lengths of old fishing line; lost line can be lethal.

72. When traveling, bring your own snack food in reusable or recyclable containers.

73. When choosing souvenirs, make sure they are not from an endangered species.

74. Participate in clean up efforts.

75. Save energy when you go away—turn down the thermostats for air conditioner, furnace, hot water heater.

Citizen Action

76. Register to vote and...VOTE!

77. Be informed on issues affecting your local, statewide and national community—Think Globally and Act Locally!

78. Read *EnviroAction* and contact your elected officials, through letters, calls, telegrams or visits, clearly communicating your concerns.

80. Attend town meetings held by local officials and national elected officials in your area.

81. Ask your church, synagogue, civic or community club to sponsor an environmental education day or environmental projects.

82. Use your local newspaper—write letters to the editor, contact a staff writer about a news story, take out an ad.

83. Volunteer on a campaign—donate time and/or money.

84. Become active in a local environmental organization and/or donate funds in support of the organization.

85. Share environmental knowledge with others.

86. Help to organize a toxic garbage pickup in your neighborhood.

87. Encourage your local government and community businesses to use sand instead of salt to de-ice streets and walkways; also to discourage excessive use of chemical fertilizers on public or commercial lawns and parks.

88. Help work on recycling programs in your community and help to educate the community about the importance of recycling.

89. Notify program directors of radio and television stations of newsworthy stories with environmental impact.

90. Organize consumer action—rewarding companies that are good environmental citizens and drawing attention to bad companies through letter-writing campaigns, meetings with company officials, press coverage or boycotts.

National Wildlife April 1993
EnviroAction

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VII

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P.O. Box 51215
Pacific Grove, CA 93950
408-648-4841

Audience: general, high school.

Articles, graphics, activities.

Marine Technology Society Journal, "Global Change," ISSN 0025-3324.

Allen Young
Marine Technology Society
1828 L Street, NW, Ste. 906
Washington, D.C. 20336
202-785-3412
Fax 202-429-9417

Audience: general.

Two issues devoted to global change. "Global Change, Part I" in MTS, Vol. 25, No. 3 and "Global Change, Part II" in MTS, Vol. 25, No. 4, 1991–92.

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Anthony R. de Souza
Editor, Research & Exploration
1600 M Street, NW
Washington, DC 20036
202-857-7766

Audience: general.

Entire issue dedicated to global warming debate, full of color images, Vol. 9, No. 2, Spring 1993.

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1-800-722-NSTA

Audience: elementary—college.

Compilation of articles from NSTA's four journals: *Science and Children, Science Scope, The Science Teacher, and Journal of College Science Teaching.* 70+ hands-on activities written by teachers plus bibliography of NSTA journal articles concerning Earth science from 1982–91. $19.95.

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Dell Publishing Group Inc.
666 Fifth Ave.
New York, NY 10103

Audience: general.

223 pages. $9.95 +$2.50 shipping.

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John Wiley & Sons, Inc.
1-800-CALLWILEY

Zero Population Growth, Inc., *For Earth's Sake: Lessons in Population and the Environment.*

Deborah Brouse and
Pamela Wasserman, ZPG
1400 16th Street, NW, Ste. 320
Washington, DC 20036
202-332-2200

Audience: middle school.

Teacher's Guide plus poster, 68 pages. $24.95 + $3 shipping.

CD ROM

CIESIN, *Windows on Global Change.*

Ralph Coppola
CIESIN
2250 Pierce Rd.
University Center, MI 48710
517-790-4295
FAX 517-790-1276

Audience: middle school.

Access to actual data sets, in production for 1995.

Earth Explorers Group, *Environmental Education Encyclopedia.*

Michael Alford
Earth Explorers Group
Sonic Images Productions, Inc.
4590 MacArthur Blvd., NW
Washington, DC 20007
202-333-1063
FAX 202-338-1386

Audience: middle school.

In development, allows examination of social issues through interactive game, data experimentation, multiple disciplines.

Educorp, *Ecodisc,* Simulation of a real nature reserve.

Educorp.
531 Stevens Ave., Ste. B
Solana Beach, CA 92075
800-843-9497

Audience: high school.

Multilingual simulation with problem solving, $250.

EPA/NOAA, *Global Ecosystems Database.*

National Geophysical Data Center
325 Broadway
Boulder, CO 80303
303-497-6125
FAX 303-497-6513

Audience: scientists.

Workshops for teachers to work with scientific data on disks. Also *Global Change Data Base for Africa* with workbook exercises for classroom and self-instruction—college.

Global Change Data Center, *Greenhouse Effect Detection Experiment*—GEDEX, DAAC User Support Office.

NASA/Goddard Space
Flight Center
Greenbelt, MD 20771
301-286-3209

Audience: scientists.

Sixty data sets—temperature, solar irradiance, clouds, greenhouse gases, fluxes, albedo, aerosols, ozone, water vapor.

NASA-Goddard, NSSDC, *Ozone,* TOMS gridded data, NSSDC Coordinated Request and Use Support Office.

Dr. Richard McPeters
NASA-Goddard
Greenbelt, MD 20771
301-286-3832

Audience: scientists.

Gridded ozone data, color images in daily and monthly averages for 1978–91 and daily zonal mean ozone updates.

National Climatic Data Center, NCAR, *World Weather Disc,* Climate Data for the Planet Earth.

WeatherDisc Assoc., Inc.
4584 NE 89th
Seattle, WA 98115
206-524-4314

Audience: scientists.

Climate data, weather data for today and the past few hundred years.

U.S. Geological Survey, Department of Interior, *JEDI*: Ozone, Sea Level.

Jim Sproull
JEDI Teacher Coordinator
USGS
Reston, VA 22092
703-648-6636
FAX 703-648-6683

Audience: middle and high schools.

Joint Educational Initiative, databases from NASA, NOAA, USGS, 2 gigabytes of world wide data and information, $35.

Wayzata Technology, Inc., *Down to Earth*, environmental themes, endangered species, marine life.

Wayzata Tech, Inc.
Prior Lake, MN
800-735-7321

1,000 PICT images, endangered species, flora, fauna, foliage, food, landscapes, marine life, $200.

COMPUTER DISKS

Earthquest, Natural systems, fragile ecosystems, environment.

Earthquest
125 University Ave.
Berkeley, CA 94301
415-321-5838

Audience: general.

Hypercard animated movies, maps, charts, Interactive games, text. $79.95.

EcoNet, *Global Warming*.

EcoNet
3228 Sacramento St.
San Francisco, CA 94115
415-923-0900

International Foundation for Survival and Development of Humanity with Apple Computer—interactive on global warming, potential impacts and mitigation strategies. $10.

Lawrence Berkeley Laboratory, *Knowledge Tree*, global climate, greenhouse.

Richard Golden
Climate Protection Institute
5833 Balmoral Dr.
Oakland, CA 94619
415-531-0100

Audience: middle and high schools.

HyperCard software for Macintosh computers, black-and-white database for study of global climate variations caused by greenhouse effect, text and some animation. $15.

National Geophysical Data Center, NOAA, *Global Change*.

NOAA, E/GC1, Dept. 891
325 Broadway
Boulder, CO 80303
303-497-6125
FAX 303-497-6513

Audience: middle school.

18 diskettes with documentation and teacher's guide.

Save the Planet Software, ozone.

Save the Planet Software Serving the Environmental Community
P.O. Box 45
Pitkin, CO 81241
303-641-5035

Audience: students and general.

Current ozone research, graphics, images, maps , formulas, 1991 Antarctic ozone hole, health and environmental risks. $24.95.

World Game Institute, *Global Data Manager*, and *Global Recall*, Population, economics, environment.

World Game Institute
3215 Race St.
Philadelphia, PA 19104
215-387-0220
FAX 215-387-3009

Global Data Manager spreadsheet, 180 variables for every country on population, food, economy, etc. *Global Recall* is hypercard 200 scaled maps and statistics in agriculture, population, environment with teacher's manual. $125 for *Global Data Manager* and $85 for *Global Recall*.

COMPUTER NETWORKS

Alliance for Environmental Education, ECO-NET.

Tom Benjamin
P.O. Box 368
The Plains, VA 22171
703-253-5812

Audience: general, schools.

Access to 300 environmental groups and federal agencies. $15 membership.

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Lelani Arris
EcoNet
3228 Sacramento St.
San Francisco, CA 94115
415-923-0900
Audience: general.
$15.

National Geographic Kids Network, "Weather in Action" and "Solar Energy."
1-800-368-2728
Collect and record data and interact via telecommunications with students around the world, $97.50/8 wk. session+ $375 kit.

Technical Education Research Centers (TERC), Global Laboratory Project.
Robert Tinker
TERC
2067 Massachusetts Ave.
Cambridge, MA 02140
617-547-0430
Audience: high school faculty and students, college faculty and students, and scientists.
Students world-wide engaged in measurement, modeling, data analysis and experimentation on global environmental problems. Access via ECO-NET.

COMPUTER SIMULATION GAMES

Accolade, "Balance of the Planet," global environmental problems.
Accolade
550 W. Winchester Blvd., Ste. 200
San Jose, CA 95128
800-245-7744
Audience: adults.
"High Commissioner of the Environment," levying taxes and granting subsidies to solve a variety of global environmental problems, $49.95.

National Diffusion Network, "Fish Banks," 1991, Dennis Meadows.
Fish Banks, Ltd.
IPSSR-Hood House
University of New Hampshire
Durham, NH 03824
603-862-2186
FAX 603-862-1488
Audience: high school and adults.
Group role-playing computer-assisted simulation for managing fishing companies, concerns management of natural resources, economics and group problem-solving, game kit for up to 50 people. $100 game kit for Macintosh or IBM, awareness video $5.

Maxis, "SimEarth," Planetary ecosystems.
Maxis
1042 Country Club Dr., Ste. C
Moraga, CA 94556
415-376-6434
Audience: high school and adult.
Can manipulate the influence of various factors on the planet.

CURRICULA

Alpha Publishing Company, Inc., "Hands-on Environmental Science Activities," closed-system biome, population.
Alpha Publishing Co.,
1910 Hidden Point Rd.
Annapolis, MD 21401-9720
410-757-5404
Audience: middle and high school.
Activities and experiments.

American Association for the Advancement of Science (AAAS), "Enviro-Links: Greenhouse Effect."
Barbara Walthall, Editor
Newsletter, AAAS
333 H Street, NW
Washington, DC 20005
202-326-6646
FAX 202-371-9849
Audience: schools, general.

One experiment (pp. 94–5) on greenhouse effect, developed for historically black colleges and minority institutions on environmental technology and waste management.

American Meteorological Society (AMS), "Project Atmosphere," Global Climate Change.

Ira Geer
AMS Education Program
Project Atmosphere
701 K Street, NW, #300
Washington, DC 20006

Audience: elementary—high school.

Background information, activities, games, teacher's guides, slide sets. Education free use.

Aspen Global Change Institute, "Ground Truth Studies."

Aspen Global Change Institute
100 East Francis
Aspen, CO 81611
303-925-7376
FAX 303-925-7097

Audience: K-12 schools.

"Global Change Primer," teacher handbook for classroom activities. $29.95.

Climate Protection Institute "Global Warming, Science and Social Studies Activities."

Richard Golden
Global Systems Science
Climate Protection Institute
5833 Balmoral Drive
Oakland, CA 94619
510-531-0100
FAX 510-642-1055

Audience: high school.

Activities and experiments in science and social studies. $9.85 each.

Concern, Inc., "Global Warming and Energy Choices."

Concern, Inc.
1794 Columbia Road, NW
Washington, DC 20009
202-328-8160

Audience: general.

Community action guide for energy conservation and efficiency, renewable energy sources, sustainable agriculture, reforestation, reduction of population growth, $5.50.

Department of Energy, "Atmospheric Carbon Dioxide and the Greenhouse Effect."

DOE/ER-0411
National Technical Information Service (NTIS)
Department of Commerce
Springfield, VA 22161

Overview, fact sheets, graphics.

Enterprise for Education, "The Greenhouse Effect and Global Warming."

John Lord
Enterprise for Education
1320-A Third Street,
Santa Monica, CA 90401

Audience: elementary—high school.

Environmental Skill Builder, background information, action ideas, color graphics and photos, Education free use in local area.

EPA, "Global Climates—Past, Present and Future."

Sandra Henderson
182 West Elm Street
Louisville, CO 80027
303-665-0767
FAX 303-665-0118

Audience: middle—high school.

Educator/scientist partnership, classroom experiments.

EPA, "Stratospheric Ozone Protection."

Information Hotline, Air and Radiation
U.S. Environmental Protection Agency
Washington, DC
1-800-296-1996

Audience: general.

Two page information sheets—"Action Guide: Cooling and Refrigerating without CFCs," "Fact Sheet: Short List of Alternative Refrigerants," "Resources: Air Conditioning and Refrigeration."

BIBLIOGRAPHY

Global Tomorrow Coalition, "Global Issues Education Set."

Walter Corson
1325 G Street, NW, Suite 1010
Washington, DC 20005-3104
202-628-4018
FAX 202-628-4018

Audience: K-12 schools.

Six teacher units with lesson plans and interactive learning activities on biodiversity, population, tropical forests, ocean and coastal resources. $65.

Global Tomorrow Coalition, "The Global Ecology Handbook: What You Can Do About the Environmental Crisis."

Walter Corson
1325 G Street, NW, Ste. 1010
Washington, DC 20005-3104
202-628-4018
FAX 202-628-4018

Audience: K-12 schools.

Basic facts about population, development and the environment, food and agriculture, biological diversity and tropical forests, fresh water and ocean resources, energy and climate, solid and hazardous wastes, and global security. $15. Study Guide—additional $15.

Great Explorations in Math and Science (GEMS), "Global Warming and the Greenhouse Effect."

GEMS
Lawrence Hall of Science
U. California at Berkeley
Berkeley, CA 94720

Audience: middle school.

Experiments, overhead masters and global warming game.

Lawrence Livermore National Laboratory, "The Greenhouse Effect: Global Climate Change Curriculum Materials."

Delores Doyle
Atmospheric & Geophysical Sciences
Science Education Center
P.O. Box 808, L-793
Livermore, CA 94551-9900
510-424-0568
FAX 510-373-1106

Audience: middle schools.

Los Alamos National Laboratory Department of Energy "SWOOPE: Students Watching Over Our Planet Earth."

Dianne Hyer
Los Alamos National Laboratory
MS D 447
Los Alamos, NM 87545
505-667-8950

Audience: K-12 schools.

Students collect data and send to laboratory to be compiled and analyzed by scientists.

Mississippi-Alabama Sea Grant, "Global Change Teaching Activities." Population, biodiversity, ozone, sea level, greenhouse, ecosystem response.

Sharon Walker
Gulf Coast Research Laboratory
Miss-Alabama Sea Grant
703 East Beach Drive
Ocean Springs, Mississippi 39564-7000
601-374-5550

Audience: middle school.

Activities designed by teachers and informal educators at climate and global change training seminars.

Modern Curriculum Press, Inc. "Ecology: Global Greenhouse," "Walk by the Seashore," "Frozen Wilderness," "Energy Book," ISSN 0-8136-4705-3, 1992.

Modern Curriculum Press
3900 Prospect Road
Cleveland, Ohio 44136

Audience: elementary.

Illustrated stories, teacher's guide, $25 each.

NASA, "Earth's Mysterious Atmosphere."

Frank Owens
Education Division
NASA Headquarters
400 Maryland Ave., SW
Washington, DC 20277-2028

Audience: middle school.

Background and activities on atmosphere and greenhouse effect.

NASA, Goddard Teacher Resource Center, "Fact Sheets," ozone, greenhouse, oceans.
Linda Matys
Teacher Resource Center, NASA
Greenbelt Rd.
Greenbelt, MD 20771
301-286-8570
Audience: schools, general.

NASA, OIES, "Earth System Science."
Office for Interdisciplinary Earth Studies
UCAR
P.O. Box 3000
Boulder, CO 80307
Audience: general.
Full-color graphics, satellite images, fact sheets, lithographs.

National Agricultural Library, USDA, "Global Change Information Packet."
Janet Wright
National Agricultural Library
USDA
Beltsville, MD 20705
301-504-5755
Audience: general.
Articles, fact sheets, bibliography.

New Explorers Series, "Crisis: Planet Earth."
Commonwealth Edison
Public Affairs Department
P.O. Box 767
Chicago, IL 60690-0767
Audience: elementary school.
Teacher/scientist partners, copy ready, accompanied by video, energy use, greenhouse effect, water treatment. Education free use.

NOAA/National Weather Service (NWS), "Weather."
Hank Robinson
Meteorology NWS
SSMC1 - 13123
Silver Spring, MD 20910
301-713-1970
FAX 303-497-6513
Audience: K-12 schools.
Teacher modules.

National Oceanic and Atmospheric Administration Office of Global Programs (NOAA/OGP)
Reports to the Nation: "The Climate System," "Our Ozone Shield," "El Niño."
Office for Interdisciplinary Earth Studies
UCAR
P.O. Box 3000
Boulder, CO 80307-3000
303-497-1682
FAX 303-497-1679
Audience: general.
Narrative with graphics.

Oak Ridge National Laboratory, Department of Energy, "The Carbon Dioxide Information Analysis Center."
Sonja B. Jones
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831
615-574-0390
FAX 615-574-2232
Audience: middle—high schools.
Trends '90, actual CO_2 data reported from collection sites. Free.

Ohio State Sea Grant, "Global Change-Great Lakes Scenarios."
Roseanne Fortner
Sea Grant
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212-1194
614-292-2265
FAX 614-292-4364
Fact sheets on climate models, water resources, biodiversity, agriculture, fish, and forests. Developing curriculum materials to accompany fact sheets.

Population Reference Bureau, "Making Connections: Linking Population and the Environment."
Population Reference Bureau
1875 Connecticut Ave., NW, Ste. 520
Washington, D.C. 20009-5728
202-483-1100
Audience: elementary.

BIBLIOGRAPHY

Smithsonian Institution, Air & Space Museum, "Blue Planet," ozone.

Carolyn Schmidt
Office of Education
National Air & Space Museum
Smithsonian Institution
Room 211
Washington, DC 20560
202-786-2106
FAX 202-786-2262

Audience: grades 3-12.

Accompanies IMAX Blue Planet, background information and classroom activities on environmental and Earth science topics.

The Ohio State University, "Activities for the Changing Earth System" (ACES), natural variability, biodiversity, ozone, sea level, greenhouse.

Rosanne Fortner
Earth Systems Education Program
The Ohio St. University
29 W. Woodruff Ave.
Columbus, Ohio 43210-1177
614-292-3750

Audience: middle and high school.

Activities, experiments, overhead masters, extensions, 291 pages, black and white. $10 + $2 shipping.

The Weather Channel & American Red Cross, "Weather," Global Climate.

Lynne D. Filderman
American National Red Cross
Washington, D.C.

Audience: general.

Background information, quizzes, pp. 10–11, available in English and Spanish.

University of Hawaii Sea Grant, "Ozone—The Hole Story."

Bruce Miller and Scott Bogle
UHSGES
University of Hawaii-Manoa
1000 Pope Rd.
Honolulu, HI 96822
808-956-8645
FAX 808-956-2858

Audience: general.

Booklet explaining what ozone depletion is and alternatives for action, includes cartoons and graphics.

University of Rhode Island Sea Grant, "Global Change Posters."

Carole Jaworski
University of Rhode Island Sea Grant
Information Office
Narragansett, RI 02882-1197
401-792-6842
FAX 401- 789-8340

Audience: elementary and middle schools.

Winners of a New England Global Change Poster Contest, total of 14 black and white posters, $1 each or $10 for packet.

U.S. Geological Survey, U.S. Department of the Interior, "Global Change."

Earth Science Information Office
U.S. Geological Survey
507 National Center
Reston, VA 22092
1-800-USA-MAPS

Audience: grades 4-6.

Classroom activities and teacher's guide on tree rings, greenhouse gasses, water, and sustainable development in the context of global change. Includes a full-color poster. Free.

World Resources Institute, "Global Environment," "Teachers Guide to World Resources."

Allen Hammond
World Resources Institute
1709 New York Ave, NW
Washington, DC 20006
202-638-6300

Audience: high school.

Activities with fact sheets, transparency masters, extensions and additional resources, Book $17.95; Teachers Guide, $4.95.

Zaner-Bloser, Inc. "Breakthroughs: Strategies for *thinking. Greenhouses—Are they always* buildings?"

Zaner-Bloser, Inc.
P.O. Box 16764
Columbus, OH 43216-6764

Audience: elementary school.

INTERNATIONAL

Bureau of Meteorology, Ozone.

Ozone Science Unit
Bureau of Meteorology
GPO Box 1289K
Melbourne, Victoria
Australia 3001
669-4000

Audience: general.

Monograph, color graphics.

Canadian Aerosol Information Bureau, greenhouse and ozone.

Canadian Aerosol Information Bureau
56 Sparks St., Ste. 702
Ottawa, Ontario, Canada, KIP 5A9

Audience: middle and high schools.

Monograph.

Earth Beat Press, Ecology Action: "Good Planets are Hard to Find."

Earth Beat Press
Station D, P.O. Box 33852
Vancouver, B.C., Canada
604-736-6931

Audience: general.

Monograph, activities to do at home.

Information Unit on Climate Change (IUCC) United Nations Environment Programme (UNEP).

UNEP/IUCC
Palais des Nations, CH-1211
Geneva 10, Switzerland
41-22-979-9244
FAX 41-22-797-3464

Audience: general.

Fact sheets with some graphics on topics of climate change causes, impacts, and international response based on IPCC scientific assessment, available in English, *Spanish, Chinese, Urdu, Japanese. Educa*tion free use.

International Geosphere-Biosphere Programme, "Global Change: Reducing Uncertainties."

Royal Swedish Academy of Sciences
Box 50005, S-104 05
Stockholm, Sweden
46 8 166 448
FAX 46 8 166 405

Audience: general.

Monograph, scientific review, print, graphic and photographic images.

UNESCO, greenhouse, ozone, population.

UNESCO, Regional Office
Asia & Pacific
P.O. Box 967
Prakanong Post Office
Bangkok 10110, Thailand

Audience: high school.

Monograph includes tables and graphs.

Visuell Inform A.S., Greenhouse, Ozone, Population, Biodiversity, Desertification, Deforestation, Global Debt.

Patricia Szczerba, Editor
Visuell Inform A.S.
Ryensvengen 7, N-0680
Oslo 6, Norway
02-67-88-00
FAX 02-67-93-51

Audience: educators.

Overhead transparencies in full color and teacher's guide. $140.

CD ROM, *GEOSCOPE,* global data sets.

Canadian Space Agency External Relations
500 Rene-Levesque Blvd. West
Montreal, Quebec, Canada
514-496-4220

Audience: middle school.

Interactive, produced in Canada, designed for Apple II.

BIBLIOGRAPHY

Report, United Nations Environment Programme, "Environmental Effects of Ozone Depletion: 1991 Update" and"Environmental Effects Panel Report."

Ozone Secretariat
K.M. Sarma UNEP
P.O. Box 30552
Nairobi, Kenya, Africa
02542-521928-29-34
FAX 02542-521930

Audience: general.

Panel Report Pursuant to Article 6 of the Montreal Protocal on Substances that Deplete the Ozone Layer. Free use.

Video, CBC TV Program Series, "A Climate for Change," global temperature balance, alternative energy sources.

Canadian Broadcasting Corporation
Box 500, Toronto
Ontario, Canada M5W 1E6
Station A
1-416-205-3500
FAX 1-416-205-3482

96-min. video, 1992, available in English.

Video, Dupont, "Saving the Ozone Layer: The Search for Solutions."

Vivian Sheridan
P.O. Box 50, Grand-Saconnex
Geneva, Switzerland
41-22-717-5111
FAX 41-22-717-5109

Sensitize industry, legislators and public to phasing out CFC's, 26-min. video, 1990, available in English, French, German, Spanish, and Italian.

Video, UNEP/IUCC, "BIOS," ballet on greenhouse effect on earth.

UNEP/IUCC
Palais des Nations
CH-1211
Geneve 10, Switzerland
41-22-789-4062
FAX 41-22-789-4073

Audience: general.

Dance interpretation with music, no text, 3-min. video, premiered at UNCED in Rio.

Video, UNEP/IUCC, "What is the Greenhouse Effect?" Computer graphics, greenhouse emissions, and global climate.

UNEP/IUCC
Palais des Nations, CH-1211
Geneve 10, Switzerland
41-22-789-4062
FAX 41-22-789-4073

Audience: general.

12-min. video, 1992, available in English, French, Spanish, Arabic.

Video, United Kingdom, BBC Enterprises, "From the Heart of the World: Elder Brothers' Warning," Kogi people in Sierra, Nevada.

Roy Gibbs
80 Woods Lane
London, United Kingdom, W12 OTT
44-81-743-5588
FAX 44-81-749-0538

90-min. video, 1990, available in English.

Video, United Kingdom, Charles Furneaux, Producer "The Big Heat," documentary on political implications of IPCC 1990 report.

Ingrid Zwartjes
TVE Distribution Center
Postbus 7, NL - 3700 AA
Zeist, Netherlands
31-3404-204-99
FAX 31-3404-224-84

40-min. video, 1990, available in English.

Video, United Kingdom, IUCN Producer, "Caring for the Earth," pollution and overconsumption, endangered forests and wetlands, ozone and greenhouse, strategies for sustainable living.

Ingrid Zwartjes
TVE Distribution Center
Postbus 7, NL - 3700 AA
Zeist, Netherlands
+31-3404-204-99
FAX +31-3404-224-84

10-min. video, 1992, available in English, French, and Spanish.

Video, United Kingdom, TVE Distribution Center, "Ozone Alert," animated film, CFC molecules are red creatures and gobble up ozone.

Ingrid Zwartjes
TVE Distribution Center
Postbus 7, NL - 3700 AA
Zeist, Netherlands,
31-3404-204-99
FAX 31-3404-224-84

5-min. video, 1990, available in English.

Video, United Kingdom, TVE and UNEP, "Climate Change: Nature's Revenge," overview of climate change, greenhouse gases, alternative energy.

Ingrid Zwartjes
TVE Distribution Center
Postbus 7, NL - 3700 AA
Zeist, Netherlands
31-3404-204-99
FAX 31-3404-224-84

10-min. video, 1992, available in English, French, and Spanish.

Video, United Kingdom, VATV Limited, "Greenhouse Conspiracy," challenge greenhouse warming, cause of CO_2, computer models.

Hilary Lawson
VATV Limited 60-62 Margaret Street
London, United Kingdom, WIN 7FJ
44-71-636-9421
FAX 44-71-436-7426

52-min. video, 1990, available in English.

Video, World Meteorological Organization, "2nd World Climate Conference," dialogue among international scientists, economists, industrialists, NGOs, media, youth.

World Meteorological Organization
Ave G. Motta 41, CH-1211
Geneve 20, Switzerland
41-22-730-81-11
FAX 41-22-734-23-26

26-min. video, 1991, available in English.

LITHOGRAPHS

NASA, EOS, "Global Change."

Lynda Matys
Goddard Space Flight Center
Earth Science, NASA
600 Independence Ave., SW
Washington, DC 20277-2028

All audiences.

Full-color satellite images.

NEWSLETTERS

Climate Protection Institute, "Greenhouse Gas-ette."

Richard Golden
Climate Protection Institute
5833 Balmoral Drive
Oakland, CA 94619
501-531-0100

Audience: high school teachers.

Announcements, background information, articles, data.

EPA, "Earth Notes."

Editor, Earth Notes
U.S. Environmental Protection Agency
401 M St. SW, A-107
Washington, DC 20460

Audience: elementary schools.

Information Unit on Climate Change (IUCC), UNEP, "United Nations Climate Change Bulletin."

UNEP/IUCC
Geneva Executive Center
CP 356, 1219
Chatelaine, Switzerland

General information, published quarterly. Free subscription and free use.

Office for Interdisciplinary Earth Studies (OIES), UCAR, "EarthQuest."

Editor, "EarthQuest"
OIES UCAR
P.O. Box 3000
Boulder, CO 80307-3000
303-497-1682
FAX 303-497-1679

All audiences.

Science Capsule insert, graphics and fact sheets. Free reprints.

The Ohio State University, "Program for Leadership in Earth Systems Education."

The Ohio State University
059 Ramseyer Hall
20 W. Woodruff Ave.
Columbus, OH 43210
614-292-7888
FAX 614-292-7812

Classroom activities, announcements, resource lists.

REPORTS

Consortium for International Earth Science Information Network (CIESIN), "Pathways of Understanding," Human Dimensions of Global Change.

CIESIN
2250 Pierce Road
University Center, MI 48710
517-797-2700
FAX 517-797-2622

Audience: social science researchers.

Social process concept map, report of workshop on human dimensions of global change.

Intergovernmental Panel on Climate Change (IPCC) Working Group 1, "Climate Change: Scientific Assessment."

J. T. Houghton
Cambridge U. Press
Cambridge, 1990

Audience: general.

Best and worst case scenarios, sea level, greenhouse, climate.

TEXTBOOKS

Kendall/Hunt Publishing, "Global Science," 3rd edition.

John W. Christensen
NR# 4x108401
2460 Kerper Blvd.
Dubuque, Iowa 52004-0539
1-800-258-5622

Includes laboratory manual.

Lawrence Hall of Science, "A Planet Under Siege," Climate Change.

Richard Golden
Global Systems Science Project
Lawrence Hall of Science
Berkeley, CA 94720

Developing a series of five volumes, *Global Systems Science.*

NASA, "Global Change Atlas of Satellite Observations."

Cambridge University Press

Release in 1993.

Prentice-Hall Science, "Exploring Earth's Weather," "Exploring Planet Earth," Ecology, ISSN 0-13-977356-8, 1993.

Englewood Cliffs, NJ 07632

Audience: middle and high schools.

Modules include cassette tapes, laboratory experiments.

Silver Burdett Press, "Weather & Climate."

John Mason,
LSB 24225-4
Silver Burdett Press
4350 Equity Drive
Columbus, OH 43216-2649
1-800-848-9500
FAX 614-771-7361

Audience: middle school.

"Our World" series, facts, and graphs.

Singing Rock Press, Larry Wade, *Oceanography*, greenhouse, ocean currents, phytoplankton, 1992.

Teachers' Laboratory, Inc.
P.O. box 6480
Brattelboro, VT 05302-6480
1-800-254-3457
FAX 802-254-5233

Audience: elementary.

Graphics, short answer, simple mathematics, sections on "Meet an Oceanographer."

VIDEO

Bullfrog Films, "Once and Future Planet."

Helen Holcomb
Bullfrog Films
P.O. Box 149
Oley, PA
215-779-8226
FAX 215-370-1978

U.S. and Soviet scientists research cloud formation and methane, 23-min. video, 1990.

Bullfrog Films, "Our Planet Earth."

Helen Holcomb
Bullfrog Films
P.O. Box 149
Oley, PA
215-779-8226
FAX 215-370-1978

17 astronauts and cosmonauts from 10 countries reflect on space/earth with images of earth 23-min. video, 1990, available in English, French, and Spanish.

Coronet/MTI, "What is an Ecosystem?"

Maslowski Wildlife
Productions, #QD-6671C
1-800-777-8100

1992, 11-min. video, $250, $75 rent.

Films for the Humanities and Sciences, "Planet Earth: Ecology & Environment," greenhouse, ozone, El Niño.

P.O. Box 2053
Princeton, NJ 08543-2053
800-257-5126
FAX 609-452-1602

Audience: general.

$150 each, $75 rent.

Louisiana Sea Grant College Program, "Global Environmental Change: An Annotated Bibliography for Visual Media."

Lyle Soniat
Louisiana State University
210A Wetland Resources Bldg.
Baton Rouge, LA 70803-7507
504-388-6565

Global change, overpopulation, acid rain, greenhouse effect, ozone depletion, sea-level rise, pollution, biodepletion.

Louisiana Sea Grant College Program, "Project Tellus."

Lyle Soniat
Louisiana State University
210A Wetland Resources Bldg.
Baton Rouge, LA 70803-7507
504-388-6565

Audience: middle school.

In development, interactive videos, six modules on exotic species, biodiversity, pollution, climate change, population, scientific inquiry.

NASA, Goddard Teacher Resource Center, "Poseidon: Mission to Planet Earth—TOPEX," Greenhouse, Ocean Circulation, El Niño.

Linda Matys
Goddard
Teacher Resource Center
Greenbelt Road
Greenbelt, MD 20771
301-286-8570

Audience: general.

9 min, 1992.

BIBLIOGRAPHY

PBS Video Series, "Icewalk."
Ja'niece Olfus-Carter
Account Representative
1320 Braddock Place
Alexandria, VA 22314
703-739-5269 or
800-424-7963 x5382
FAX 703-739-5269

S.C. Johnson Wax, "Ozone: The HOLE Story."
S. C. Johnson Wax
Racine, Wisconsin
Aired on PBS nationwide, video with accompanying teaching unit.

The Video Project, "Greenhouse Crisis: The American Response."
Union of Concerned Scientists
The Video Project
5332 College Ave., Ste. 101
Oakland, CA 94618
11-min. video, 1989, $20.

University of Wisconsin Bureau of Audio-Visual Instruction (BAVI), greenhouse effect, ozone, El Niño, oceans.
BAVI
University of Wisconsin
P.O. Box 2093
Madison, WI 53701-2093
608-262-3902
Coronet: "Global Environment Video Series," 1990-91, two in the series on greenhouse effect, both 20 min. "The Hole in the Sky," (IUCC) NOVA, 58 min., 1987. "Ocean and Climate," Oceanography Video Series, 26 min., 1989. "The Return of the Child: The Effects of El Niño," (IUCC) 26 min., 1990.

University of Rhode Island, "Interviews with experts," greenhouse, population, consumption, policy, persuasion.
Lynne Carter
Special Assistant for Global Change
Graduate School of Oceanography
Narragansett Bay Campus
Narragansett, RI 02882
401-792-6211
Audience: high school, college.
Interviews in 30-min. segments, with leading scientists including Kellogg, Rowland, Moore, Fouts, Sanchez, Evans, Mintzer, and Clark.

Video Project, "Spaceship Earth."
Karriann Farrell
Video Project, Ste. 101
5332 College Ave.
Oakland, CA, 94618
510-655-9050
510-655-9115
Educating young people on deforestation, global warming and ozone, 25-min. video, 1990.

Western Fuels Association., Inc, "The Greening of Planet Earth."
Western Fuels Association Magruder Bldg.
1625 M Street, NW
Washington, DC 20077-0036
202-463-6580
FAX 202-223-8790
Argues that CO_2 will enhance growth of trees and other plants, 28-min. video, 1991.

WQED Pittsburgh & National Academy of Sciences, "Planet Earth," "The Blue Planet," "The Climate Puzzle."
Annenberg/CPB
1-800-LEARNER
Released 1986, updated since, includes text and teacher's guide, Discovery Interactive Library, Coronet/MTI videodisc, $29.95.

Zero Population Growth, Inc. "World Population."
Deborah Brouse and
Pamela Wasserman
ZPG
Washington, DC 20036
202-332-2200
Audience: general.
Graphic simulation of the history of human population growth, 8-min. video.

VIDEODISC

Environment Videodisc Project, "Our Environment."

Environment Videodisc Project
Department of Geography and Geology
University of Wisconsin-Stevens Point
Stevens Point, WI 54481
715-346-4450

Audience: middle school.

Human impacts on environment.

IBM EduQuest, "Science 2000: Ecosystems."

William Swem
Direct Response Marketing
P.O. Box 3974
Peoria, IL 61612

Audience: middle school.

Two laserdiscs with 750 still images, access to online databases, $4,100.

National Geographic Ed-Tech, GTV: "Planetary Manager."

800-368-2728

$595.

WGBH Interactive Projects, Interactive NOVA: "Race to Save the Planet," greenhouse, ozone, climate, biodiversity.

Education Foundation Scholastic, Inc.
125 Western Ave.
Boston, MA 02134
617-787-1639
FAX 617-787-1639

Audience: middle—high schools.

In production: "NOVA: Earth," in cooperation with NASA, interactive videodisk. $395, $195 library, 30-day free trial.

GLOBAL CHANGE EDUCATION
RESOURCE GUIDE

SCRIPTS FOR
COLOR OVERHEAD
TRANSPARENCY MASTERS

#1

"Forecasting Time Scales and Human Impacts"

What is it?

Time scales that vary from hours to centuries are used in forecasting and recording weather and climate. The number of people affected by weather and climatic events also vary on a scale from very local (i.e., a relatively few number of people) to a global perspective (i.e., billions of people being impacted).

Note: "synoptic" is a term meteorologists use to mean "everywhere at the same time."

Why do we care?

We need to extend our thinking about climate from a regional, present-oriented mode to a global, long-term mode. Our present activities can affect climate over the long term and can impact many people beyond our political and geographical boundaries. Understanding and interpreting local weather data and understanding their relationship is a very important first step to understanding larger-scale global climate changes.

Resource Guide Reference:

Pages I-1, I-3, I-5, I-7, I-9

#2

"Sources of Climate and Global Change"

What is it?

Many factors, both natural and anthropogenic (human-made), determine earth's climate and global environmental change.

Why do we care?

"Natural variability" includes natural occurrences in the environment which contribute to climate fluctuations and global change. Natural factors can include, but are not limited to the following.

1. Atmosphere: sun (energy, orbit, tilt, cycles), reflection (albedo), clouds, precipitation, wind, gases (H_2O vapor, CO_2, CH_4), feedbacks, and cycles.
2. Geosphere: geography (mountains, water sources), volcanoes, surface roughness, earth's core heat, feedbacks.
3. Biosphere: living organisms, carbon storage and cycling, evaportranspirations, surface roughness, and feedbacks.
4. Hydrosphere: currents (El Nino), surface roughness, ice sheets, cycles, feedbacks.

"Human activities" includes factors which are a direct result of our activities on the planet. As population increases, there are more people participating in activities that contribute to global environmental change. For example, the burning of fossil fuels (oil, coal, wood) results in waste products (additional greenhouse gases being released) which both pollute the air that we breathe and contribute to an enhanced greenhouse effect. Slash and field burning, deforestation, agriculture, destruction of wetlands, building of cities and industries are examples of land use practices that can impact the environment.

Resource Guide Reference:

Pages I-61, I-9, II-1, II-2

#3

"Climate System"

What is it?

The climate system is a tremendously complex system. It is governed not only by what happens in the atmosphere, but in the oceans, the cryosphere (glaciers, sea ice, and continental ice caps), the geosphere (the earth's solid surface) and the biosphere (living organisms in the oceans and on land). The interactions among these various "spheres" are difficult to predict, not least because their respective processes occur on widely differing time scales. The typical response times of the climate system's various components range from a single day to millennia.

Why do we care?

If we are interested in understanding and predicting changes in global climate, we must examine the relationships among the various components. Much more research is needed to enable scientists to better predict how climate change will come about. We need to better understand the various climate-related processes, particularly those associated with clouds, oceans, and the carbon cycle.

Resource Guide Reference:

The above information was directly quoted from "An Introduction to the Climate System", IUCC, page I-1.

#4

"Great Ocean Conveyor Belt"

What is it?

This is a highly generalized graphic conceptualization of how ocean currents circulate around the globe. The key point is the air-to-sea transfer where cold water sinks to the deep ocean carrying CO2 and depositing it on the ocean floor for long-term storage.

Why do we care?

Deep-ocean currents affect long-term climate variations. Over most of the oceans, surface water is warmer (and less dense) than the water beneath it. This discourages surface water from sinking downwards into the deep ocean. Only in certain regions, notably in the Antarctic and northwest Atlantic Oceans, does a combination of evaporation (which increases the water's salt content) and wintertime cooling make surface water dense enough to sink all the way down. This process of "deep-water formation" is still not fully understood, but it is clearly important. It is the primary mechanism whereby heat and absorbed CO_2 and dissolved carbon in surface water is transported down to the ocean depths, where they may remain for thousands of years. Changes in deep ocean currents may have caused natural climate fluctuations in the past, and their role in storing or releasing "excess" carbon could interact with human-induced climate change in the future.

Resource Guide Reference:

The above information was directly quoted from "An Introduction to the Climate System", IUCC, page I-1.

#5

"Surface Hydrology in Some General Circulation Models"

What is it?

This slide depicts the complexity of information needed in only one small part of a General Circulation Model (GCMs). GCMs are complex mathematical representations of ocean-atmospheric relationships that help to understand global and regional climates. These models are the primary tools used by scientists to explore and understand the current planetary climate, and to predict what future climates might be like.

Why do we care?

To better understand and predict future climate scenarios, it is necessary to consider the complex structure and function of all climate-related processes (including the surface hydrology shown in this slide). This slide gives a general view of how water moves over and away from the earth's surface. Note that vegetation on earth (represented by the tree on the slide) has an important influence on the movement of water to and from the atmosphere. Global changes in the amount and types of vegetation can have an impact on hydrologic circulation and thus on climate and weather patterns.

Resource Guide Reference:

Page VI-23

#6

"Ocean-Atmosphere Circulation in El Nino Southern Oscillation (ENSO)"

What is it?
Note: This slide does not depict an El Nino Event but simply sets the stage for further discussion.

This a generalization of the ocean-atmosphere circulation in the equatorial zone between South America and Asia. It is in this part of the world that the interconnected set of patterns know as El Nino-Southern Oscillation (ENSO) are found. Taken together, they provide the best known example of how the ocean and atmosphere are interconnected.

Why do we care?

El Nino refers to the linked ocean and atmospheric events, which are characterized by a relaxation of the usually intense westward trade winds. These trade winds "pile up" warm surface water in the western Pacific, exposing cold water on the surface in the eastern Pacific. When the trade winds relax, warm surface waters that have been "piled up" in the western Pacific surge eastward. This creates higher than normal sea-surface temperatures in the eastern Pacific, which can lead to heavy rains and flooding. Coastal and equatorial upwelling of sea water ceases, disrupting cold water fisheries and impacting ecological processes.

The Southern Oscillation is an interannual (year to year) process in which atmospheric pressure increases on one side of the Pacific and decreases on the other, and then reverses. For example, when air pressure is low around Australia, it's high to the east around Tahiti. When the air pressure is high around Australia, it's low around Tahiti. The Southern Oscillation is correlated with major changes in rainfall patterns and wind fields over the tropical Pacific and Indian Oceans, and with temperature fluctuations in southeastern Africa, southwestern Canada, and the southern U.S..

ENSO is part of a huge and complex ocean-atmosphere system that has global impacts. Taken together, they have widespread effects, typically increasing rainfall in South America, but causing draught in much of Africa, South East Asia, and Australia.

Resource Guide Reference: Page I-13

#7

"Normal & El Nino Conditions"

What is it?

This cross-sectional graphic compares normal conditions with El Nino conditions in the equatorial Pacific Ocean.

In a normal year, intense westward winds drive westward equatorial currents that push warm Pacific surface waters steadily to the west and expose colder waters, upwelling from the deeper water column, to the surface in the east.

In an El Nino year, the trade winds relax, allowing a surge of warm water eastward across the Pacific and changing the characteristics of waters in the eastern part of the Pacific Ocean basin.

Why do we care?

The changes associated with El Nino events can lead to heavy rains and flooding in some parts of the world, while causing draught in other parts of the world. In addition, coastal and equatorial upwelling of sea water ceases, disrupting cold water fisheries off the coast of South America and impacting ecological processes.

Resource Guide Reference:

Page I-13

#8

"Atmospheric Water Vapor"

What is it?

This is a computer-enhanced representation comparing the amount of atmospheric water vapor around the equator in the Pacific during a "normal" year to the amount of rainfall during an El Nino event.

Why do we care?

During an El Nino event, there is an increase in atmospheric water vapor in the more western longitudes which indicates warmer water temperatures.

Resource Guide Reference:

Page I-13

#9.

"Atmospheric Particles"

What is it?

This graph illustrates the impact on the atmosphere of particles emitted by volcanoes as a result of eruption during the past two decades.

Why do we care?

Great quantities of dust, ashes, CO2, and sulfur dioxide are released into the atmosphere during a volcanic eruption. This can cause short-term cooling due to blockage of incoming solar radiation. The dust and particles can be carried all around the globe by upper level atmospheric winds, thus impacting climate over a large area for as much as four years after the eruption.

Note: The "nrbs" stands for non-rayleigh back scatter. The "(sr-1)" is the units of per steradian. The data is from a lidar (laser radar) which fires a laser beam in the vertical and then waits for the reflected signal to return. If there is no aerosol the reflected signal is from rayleigh scattering (atomic and molecular scattering in the atmosphere). If there is aerosol overhead then more of the signal is reflected back. This is a qualitative indicator of particles above. The units on the axis means that the total column has been integrated. Usually the lidar signal is inverted into a profile (i.e. aerosol concentration vs height) but in this case the profile has been integrated to get the total.

Resource Guide Reference:

I-62-71

#10

"Global Temperature and Atmospheric Carbon Dioxide"

What is it?

Data from the Vostok Ice-core reveal a correlation between CO_2 concentration in the atmosphere and temperature change over the past 160,000 years.

Why do we care?

Many scientists believe that much can be learned about potential future changes in climate by examining past climatic change. One method to study past climates is through the analysis of glacial ice cores. Ice cores provide information about past atmospheric composition based on tiny samples of air trapped in the glacial ice. Since the early 1970s, French and Soviet scientists have collaborated on research at Vostok in Antarctica to drill and examine the deep ice cores. Studying the Vostok core has shown a positive relationship between increases in CO_2 and warm periods of the earth's past, as well as correlations between ice ages and low amounts of atmospheric CO_2.

In addition to CO_2 levels, other information available from analyses of ice cores includes other greenhouse gases (e.g., methane), dust deposition rates (indicating volcanic activity and changes in the extent of desert regions), solar activity (from beryllium-10 analyses), and the availability of cloud condensation nuclei (from plankton-derived sulfur compounds).

Resource Guide Reference:

Pages I-10, I-41-45

#11

"The Global Greenhouse"

What is it?

This is a graphic representation of the greenhouse effect. The ability of certain trace gases (e.g. water vapor, CO_2, CH_4) to be relatively transparent to incoming visible light from the sun, yet opaque to the energy radiated from the earth is one of the best understood processes in atmospheric sciences (known as the greenhouse effect). About 70% of the sun's energy that enters the atmosphere reaches the earth (about 30% is reflected back into space). Greenhouse gases act as a "blanket" and trap the outgoing heat energy thus warming the earth.

Why do we care?

Many scientists believe that human activity is altering the composition of the atmosphere by increasing the concentration of greenhouse gases. It is important to remember that the greenhouse effect is what keeps earth warm enough to be habitable. The current concern is directed at an ***enhanced*** greenhouse effect, one that would put more heat-absorbing gases into the atmosphere and thereby increase global temperatures. The enhanced greenhouse effect has been linked to human activities that result in increased greenhouse gas emissions. Specific human activities include the burning of fossil fuel, deforestation, building and maintaining rice paddies, and industrial processes and emissions.

Resource Guide Reference:

Page II-13

#12

"How the Greenhouse Effect Works"

What is it?

This a generalized drawing of the greenhouse effect. The ability of certain trace gases (e.g. water vapor, CO_2, CH_4) to be relatively transparent to incoming visible light from the sun, yet opaque to the energy radiated from the earth is one of the best understood processes in atmospheric sciences (known as the greenhouse effect). About 70% of the sun's energy that enters the atmosphere reaches the earth (about 30% is reflected back into space). Greenhouse gases act as a "blanket" and trap the outgoing heat energy thus warming the earth.

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Specific human activities include burning of fossil fuels, deforestation, building and maintaining rice paddies, and industrial processes and emissions.

Resource Guide Reference:

Pages II-1, II-3, II-5

#13

"Global Mean Temperature"

What is it?

This graph shows deviations from a global temperature of 15°C for the period from 1854-1990. Global temperature records exist only for the past century or so. The data available to researchers looking for temperature trends are land-based air temperature measurements and marine air-temperature and sea-surface temperature records. All begin around 1860.

Why do we care?

Much of the warming since 1900 has been concentrated in two periods, the first between 1910 and 1940 and the other since 1975; the five warmest years on record have all been in the 1980s. Almost all of the climate models suggest that the world's average surface temperature ought to have warmed somewhere between 0.4°C and 1°C since pre-industrial times as a result of the greenhouse gases emitted so far. So, it follows, that one of the clearest signs of human-induced climate change would be the detection of such a warming. The graph on this slide does seem to show such a warming trend. However, such data must be interpreted carefully. Natural climate variations must also be taken into account. Unambiguous detection of climate change is likely to be a painfully slow process, involving much more detailed comparison of climate model results with observations.

Resource Guide Reference:

Portions of the above were quoted directly from "Why three hot summers don't mean global warming" (IUCC), page I-5.

Page VI-29

#14

"Global Distribution of Atmospheric Carbon"

What is it?

Three-dimensional representation of the global distribution of atmospheric carbon dioxide.

Why do we care?

Atmosphere carbon dioxide content has risen steadily, and also varies considerably between the Northern and Southern hemispheres. This is due both to greater industrialization in the Northern hemisphere and to greater vegetation coverage. It is the role of vegetation that accounts for the annual peaks and valley in carbon dioxide levels. This has been referred to as the "breathing of the earth. During the summer growing season atmospheric carbon levels drop because plants take up CO2 and store it as plant tissue (wood, leaves). During the winter plants do not take up carbon, and fallen leaves decompose releasing some stored carbon.

The vertical axis measures CO_2 concentrations in parts per million (PPM).

Resource Guide Reference:

Page II-25

#15

"Greenhouse Effect"

What is it?

The inset graph shows the concentration of carbon dioxide in the atmosphere from 1958 to mid-1990, measured at the Mauna Loa Observatory on the Island of Hawaii. The annual changes are due to the respiration of plants in the Northern Hemisphere. This set of measurements, made by Charles Keeling of the Scripps Institution of Oceanography, is the longest continuous record. Since Dr. Keeling began his measurements in the 1950s, average annual CO_2 levels have increased from 315 parts per million (ppm) to over 350 ppm. This trend suggests the amount of CO_2 in the atmosphere will likely continue its increase.

Why do we care?

CO_2 is an important greenhouse gas. If the concentrations of atmospheric CO_2 continue to increase, global temperature could also increase. While the changes are uncertain, many scientists predict that temperature increases would result in changed rainfall patterns, increased severe weather events, and a rise in sea level. The potential impacts of such events could effect agricultural productivity, natural ecosystems, coastal flooding, desertification, and have deleterious effects on human health.

Resource Guide Reference:

Page II-13, II-25

#16

"Changes in Global Atmospheric Composition"

What is it?

According to this graphed data, there is a clear increasing concentration of CO_2, CFCs, and CH_4 in the atmosphere. All of these trace gases have the ability to absorb heat energy and thus warm the earth.

Why do we care?

The recent attention given to the greenhouse effect and global warming is based on the recorded increases in concentrations of some of these trace gases due to human activity.

Anthropogenic Sources:

Carbon dioxide (CO_2) is considered to be the most important greenhouse gas. It arises primarily from the burning of fossil fuels and the burning and clearing of forested land for agricultural purposes.

Chlorofluorocarbons (CFCs) have no natural source: they are produced entirely by human activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

Methane (CH_4) is largely a product of natural biological processes, but their output can be accelerated by human activities. CH_4 is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g. ruminants). The additions from human activities include expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

Resource Guide Reference:

Page II-1, II-5, VI-14-18

#17

"Atmospheric Methane Concentrations"

What is it?

Although relatively stable for most of the past 3000 years, there has been a rapid increase in atmospheric methane concentrations in the past century or so. For a thousand years prior to the industrial revolution, the concentration of methane in the atmosphere was relatively constant. However, as the world's population increased, as the world became more industrialized and as agriculture developed, the abundance of methane has increased markedly. This data was taken from ice cores in Greenland and the South Pole.

Why do we care?

Methane (CH_4) is an important greenhouse gas. As with all of the greenhouse gases, methane has the ability to absorb heat energy and contribute to the warming of the earth. Methane is largely a product of natural biological processes, but their output can be accelerated by human activities. CH_4 is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g. ruminants). The additions from human activities include expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

Resource Guide Reference:

Page II-1, II-5, VI-14-18

#18

"Sources & Composition of Greenhouse Gases"

What is it?

Note: The title of this slide is misleading as there are many more than five greenhouse gases (e.g. the main greenhouse gas is water vapor but is not directly affected by human activity). This slide depicts five important greenhouse gases that are associated with human activity.

Carbon dioxide (CO_2) is considered to be the most important greenhouse gas. It arises primarily from the burning of fossil fuels and the burning and clearing of forested land for agricultural purposes.

Chlorofluorocarbons (CFCs) have no natural source: they are produced entirely by human activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

Methane (CH_4) is largely a product of natural biological processes, but their output can be accelerated by human activities. CH_4 is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g. ruminants). The additions from human activities include expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

Ozone (O_3) found in lower altitudes (not to be confused with O_3 levels in the stratosphere) are the result of gases such as carbon monoxide, the oxides of nitrogen (all found in car exhaust fumes), methane, and other hydrocarbons.

Nitrous Oxide (N_2O) is emitted from coal-burning power plants and can be released from the breakdown of chemical fertilizers in the soil.

The major human activity that is responsible for increased greenhouse gas emissions is the burning of fossil fuel. Other human activities that contribute to increased levels of greenhouse gases are deforestation, industrial processes and agricultural practices.

Resource Guide Reference: Page II-1, II-5, VI 19-22

#19

"Greenhouse Index: Countries with Highest Greenhouse Gas Emissions, 1989"

What is it?

This bar graph shows which countries are responsible for the highest level of greenhouse gas emissions (1989).

Why do we care?

From this graphic, it is clear that the industrialized nations had the highest percentage of total global greenhouse gas emissions. in 1989.

Resource Guide Reference:

#20

"World Population Growth, 900 AD - 1990 AD"

What is it?

Human population is growing exponentially, and is a primary driving force in the increase of greenhouse gases in the atmosphere and other environmental concerns both locally and globally.

Why do we care?

World population in 1994 is approximately 5.6 - 5.7 billion and growing at over 94 million people per year.

At current growth rates our population will double in less than 50 years.

Population and resource use patterns must be considered in tandem. While most of the growth in sheer human numbers is occurring in the developing world, industrialized countries consume a far greater percentage of the world's resources.

Resource Guide Reference:

#21

"Projected Population of the World, 1990 - 2150"

What is it?

Decisions we make in the next few years will have a tremendous effect on the growth of human population and therefore on our impact on the global environment.

Why do we care?

These varying scenarios will be the result of differing policy decisions. Human population growth is a very sensitive issue with many cultural and religious implications and responses.

Resource Guide Reference:

#22

"Distribution of Tropical Forests"

What is it?

The highlighted area in this slide shows the distribution of tropical forests. The inset bar graph represents the extent of tropical deforestation cleared annually (in millions of acres) It is important to review the inset note that explains changes in deforestation rates since the publication of this graphic.

Why do we care?

Tropical forests are richer in species than any other terrestrial habitat. Closed tropical forests contain at least 50 percent and perhaps 90 percent of the world's species, although they cover only 7 percent of the earth's land surface. They include two thirds of the worlds vascular plant species and about 30 percent of its terrestrial vertebrate species. Up to 96 percent of the world's arthropods may be found in tropical forests. The destruction of tropical forests has pushed many species into extinction.

Tropical forests are important not only as the home to myriad plant and animal species, and as the source of valuable products, but also because they support diverse human cultures. Tropical forests also regulate vital biological, geological, and chemical cycles.

Tropical forests have been referred to as the earth's "lungs". The profuse biomass found in tropical forests removes enormous quantities of CO_2 from the atmosphere through photosynthesis acting as a carbon "sink". Through the common practice of slash-burning the forest to make way for agricultural lands, the stored carbon is released back into the atmosphere, adding to the concentration of atmospheric CO_2.

Resource Guide Reference:

Portions of the above text were directly quoted from "Status of Selected Habitats", World Resource Institute, page V-21

#23

"Future Greenhouse Gas Trends Under Double CO_2 Conditions"

What is it?

Note: This title may be confusing in that CO_2 is a greenhouse gas. Climate simulations using General Circulation Models (such as the Goddard Institute for Space Studies (GISS) model used for this projection) suggest that the production of greenhouse gases (e.g. carbon dioxide, nitrous oxide, methane, and CFCs) from anthropogenic activities could cause changes in the global climate. GCMs of the earth's atmosphere are a tool that scientists use in making quantitative estimates of climate variables such as temperature and precipitation. GCMs have been used to simulate the possible effect on global climate given a doubling of CO_2 concentrations.

This bar graph shows greenhouse gas concentrations from the 1950s to the 1980s and projected concentrations though the 2020s. The Y axis depicts temperature change in degrees Fahrenheit.

Why do we care?

From this graphic, it is clear that an increase in greenhouse gas concentrations are closely associated with a rise in global temperature. It is important to remember that GCMs are scientific tools - not crystal balls - and there is a great deal of uncertainty in the output of GCMs. However, most scientists agree that continued greenhouse gas emissions could result in a warmer earth.

According to the IPCC report, "We calculate with confidence that atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide, and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for the centuries ahead. The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations to stabilize at a given level. The long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's level; methane would require a 15-20% reduction."

Resource Guide Reference: Pages VI-1, VI-7

#24

"Causes of Relative Sea Level (RSL) Change"

What is it?

There are two primary causes of changes in sea level:

Vertical Land Movement

a) isostatic adjustment - changes in the level of the land
b) tectonic effects - the surface of the earth is divided into plates which are in constant motion, bumping into or slipping over or under each other
c) sedimentation - sediments are washed to the coast via run-off into rivers and streams, melting of ice-sheets and glaciers.
d) human factors - groundwater and oil extraction (example - In Los Angeles, land is being lowered due to oil extraction, resulting in sea level rise.

Changes in the Level of the Ocean's Surface

a) more water enters the oceans via melting glaciers and ice sheets
b) ocean currents and tides
c) changes in the water cycle
d) expansion of the water itself due to warming (or contraction, if the climate cools and ice sheets extend).

Why do we care?

An accelerated rise in sea level would inundate coastal wetlands and lowlands, increase the rate of shoreline erosion, exacerbate coastal flooding, raise water tables, threaten coastal structures, and increase the salinity of rivers, bays, and aquifers.

Resource Guide Reference:

Pages III-1, III-3, III-7, VI 30-32

#25

"Factors Projected to Contribute to Sea Level Rise from 1985 to 2030"

What is it?

This slide represents factors that could contribute to sea level rise in the future. Over the past 100 years, sea level has risen 10 - 20 centimeters. Scientists are now predicting that in the next 50 years the rate will double.

Why do we care?

This projected doubling is attributed to the following:
Thermal expansion (in oceanic thermal expansion, as the water molecules are warmed, the volume of water increases) would account for most of the projected sea level rise if global temperatures increase as predicted. Mountain glaciers would account for 49% of the sea level rise, whereas in the past 100 years melting has accounted for only a small portion of the rise in sea level. The melting of the Greenland ice cap would contribute about 12% of the increase. It is interesting to note that the Antarctic might even cause sea level to fall. Some scientists are now predicting that as the temperature warms and there is more moisture in the atmosphere, there will be more snow at the poles, therefore more cooling at the poles and a projected decrease melting (this accounts for the negative value attributed to the Antarctica ice shield).

Floating ice caps (e.g. those found in the Arctic Ocean) are not expected to have an impact on sea level because this ice is already floating, thus displacing its volume in the water.

Resource Guide Reference:

Pages III-3, III-13, VI 30-32

#26

"Atmospheric CO_2 and Sea Level Rise"

What is it?

Global Mean Sea Level from 1881 to 1980 has generally paralleled the rise in atmospheric CO_2. If the CO_2 concentration continues to rise at the present rate and if rising sea levels continue to parallel that trend, sea level is projected to rise at a rate of 50 centimeters per 100 years rather than the 20-20 centimeters that has been recorded in the last 100 years.

Why do we care?

Higher sea levels threaten low-lying coastal areas and island countries. Bangladesh and the Maldives Islands are examples of lands that would be at terrible risk for loss of life, homes, and businesses. Groundwaters are already becoming saline in some locations through salt water intrusion that accompanies subsidence. Estuarine habitats would be changed with a greater influx of salt water and intertidal communities would be moved to high elevation where they would have to compete with development. Damage due to floods would be more severe in the coastal areas where much of the world's population will be located in the next century. Economic and habitat loss for humans as well as plant and animal species would be extensive.

Resource Guide Reference:

Pages III-3, III-7

#27

"Sea-Level Rise Scenarios"

What is it?

This graph shows the sea level rise expected from 1900-2100 under a "business as usual scenario" emissions (no cutting back on human-induced emissions). Shown is the best estimate and range. The high estimate indicates that we could have an average rise globally of a little more than a meter; the low estimate indicates about another 20 - 20 centimeter rise (much like that of the past 100 years). There will be significant regional variations.

Why do we care?

As with most projections, there is a great deal of uncertainty in what will actually happen. snow level accumulation in Antarctica could moderate the net sea level rise. Sea level will rise at different rates in different parts of the world due to local coastline variations, changes in ocean currents, regional land subsidence and emergence, and differences in tides and water density.

Resource Guide Reference:

Page VI-30

#28

"The Ozone Layer"

What is it?

Ozone is a form of oxygen. In the lower atmosphere, oxygen is usually found in molecules composed of two atoms of oxygen. This molecule, abbreviated 0_2, is the common form of oxygen that we need to breathe. Ozone is a more unstable and uncommon molecule made up of three oxygen atoms and is abbreviated 0_3. The Ozone layer is found in the stratosphere between 15 and 25 miles above the Earth's surface.

Why do we care?

The Ozone Layer acts as a protective screen, filtering out the sun's harmful ultraviolet (UV-B) rays. Life on Earth as we know it has evolved to depend on this screen, and many life forms could be severely affected is this protective screen is significantly weakened.

Although ozone is a greenhouse gas, the destruction of the ozone layer is a different atmospheric phenomena than concerns a possible enhanced greenhouse effect. In this slide, the Ozone Layer screens out much of the incoming UV-B radiation, while the visible light penetrates through and is absorbed by Earth. Much of this infrared radiation is trapped in the lower atmosphere by the greenhouse gases and is responsible for the Earth being warm enough to sustain life as we know it.

Resource Guide Reference:

Portions of the above text were taken from "The Hole Story" UNH

Page IV-1, IV-9

#:29

"How is Ozone Destroyed?"

What is it?

Ozone depletion is a cyclical process. This slide shows the journey of a chlorine atom released from a CFC molecule and its destructive path in the upper atmosphere. Each chlorine atom from a CFC molecule has the potential to destroy tens of thousands of ozone molecules.

Why do we care?

In the natural functioning of the atmosphere, the creation and destruction of ozone occurs in equilibrium. In recent decades, human activity and the release of chemical compounds that find their way into the upper atmosphere have disrupted the natural equilibrium. Specifically, the release of compounds containing chlorine and bromine are attacking the ozone layer. The most common of these human-generated compounds are chloroflourcarbons (CFCs) and bromoflourocarbons (halons). Because of their stable chemical structure, these compounds don't break down in the lower atmosphere. They take five to ten years to reach the stratosphere, where they are broken down by intense UV radiation. This breakdown releases atoms of chlorine (from CFCs) or bromine (from halons) that react with and destroy ozone. At certain times of the year and over certain parts of the globe, ozone in the stratosphere is being destroyed slightly faster than it is being created.

Resource Guide Reference:

Portions of this text were taken from "The Hole Story", UNH

Pages IV-1, IV-9

#30

"Ozone Depletion"

What is it?

This sequence of color-coded images shows the decline in the amount of ozone in the upper atmosphere over Antarctica (the expanding black spot represents ozone value; the larger the spot, the less ozone found in the stratosphere) in October from 1980 to 1992.

Why do we care?

World-wide attention was given to the "discovery" of the "ozone hole" over Antarctica in the early 1980s. This highly publicized atmospheric phenomena is observed annually each October during the Antarctic spring. After several weeks, the Antarctic vortex, a whirling weather system that encircles and isolates the South Pole during winter, breaks up, and ozone levels rapidly rise. In meteorological terms, the Antarctic ozone hole is a significant ozone minimum and not a literal "hole" through the ozone layer. Nevertheless, for a brief time ozone levels within the hole can plummet to 150DU or even lower.

Resource Guide Reference:

Page IV-1, IV-9

#31

"Production and Uses of CFC Gases"

What is it?

This slide depicts the production and uses of CFC gases from 1960 to 1988. Chlorofluorocarbons (CFCs) are a category of gases that include molecules of chlorine, flourine, carbon, and bromine. CFCs have no natural source: they are produced entirely by human activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

Why do we care?

CFC production and use has been heavily influenced in the last 20 years by scientific research and subsequent policy decisions. In the mid-1970s (left bar graph), the largest application of CFCs was found as propellants in aerosol sprays. The use of CFCs in aerosols was banned in the United States and several other countries in 1978, which led to a temporary drop in CFC production. However, other uses of CFCs were rapidly expanded, including refrigeration, foam blowing, and solvent applications which led to a large overall increase in CFC production throughout the 1980s.

Since the passage of the Montreal Protocol and its London and Copenhagen Amendments, CFC production has decreased by over 50%. As a result of this, scientists are beginning to detect a leveling off of CFC concentration in the atmosphere.

Resource Guide Reference:

Pages IV-1, IV-9, VI-14 - VI-21

#32

"Marine Ecosystem Food Web"

What is it?

This slide provides a generalized example of the biological food web in a marine ecosystem. The biological food web in marine ecosystems starts will the primary producers - mainly the phytoplankton. Primary consumers utilize the biomass the phytoplankton produce, and are themselves food input for the next level in the food web. Because of their need for the sun's energy, phytoplankton are restricted to the upper layers of their oceanic environment. Mutual shading, absorption, and light scattering prevent effective light penetration below a certain depth where phytoplankton cannot survive.

Why do we care?

Climate change implications:

Climate change will affect phytoplankton, and vice versa. Warmer temperatures may benefit some species and hurt others. Changes in CO_2 levels may not have a direct impact, but related "feedback loops" could be important. For example, because plankton create a chemical substance called dimethysulfide (DMS) that may promote the formation of clouds over the oceans, changes in plankton population could lead to changes in cloudiness. At the same time, more clouds would reduce the amount of solar radiation reaching the oceans, which could reduce plankton activity.

Increased UV penetration implications:

The depletion of the ozone layer by CFCs would increase the amount of ultraviolet light reaching the ocean surface, which could have negative effects on the plankton. Ultraviolet radiation damage to the primary producers will have dramatic consequences because these organisms produce more than one-half of the earth's biomass.

Resource Guide Reference:

The above information was directly quoted from "Oceans and the carbon cycle" page V-3 and "Aquatic ecosystems", page V-7

#33

"Coastal Population by 2010 in Continental U.S."

What is it?

This slide projects the portion of U.S. population living in coastal areas by 2010 compared with the total U.S. land area. Although coastal areas account for only a small portion of total U.S. land area, almost half of the U.S. population is projected to be living in coastal areas by 2010. It is expected that coastal areas will have 394 persons per square mile as compared to 95 persons per square mile for the rest of the U.S. land area.

Why do we care?

The coastal areas may be hit with a "double-whammy", that is, increased pressure from population growth and development, and from changes associated with sea level rise. Even without the implications of sea level rise, coastal areas in this country are heavily impacted by population and subsequent development pressures. Shoreline erosion, loss of wetlands, salt water intrusion, loss of important wildlife habitat, pollution, and changes in upland areas are all a result of increased development in coastal areas.

Resource Guide Reference:

Page III-7, V-23

#34

"Plankton Production"

What is it?

The darker green areas on this slide represent areas with high plankton productivity.

Why do we care?

Planktonic marine organisms account for over one-half of the total, global amount of annual fixed carbon. Any reduction in this productivity will undoubtedly affect the global food supply and global climate.

Resource Guide Reference:

Page V-11

#35

"Earth at Night"

What is it?

Text taken directly from the Earth at Night" poster:

A tapestry of city lights and rural fires announces our presence on this planet. In contrast to daytime images, where only natural features are easily visible, the activities of humankind at night are readily traced in this mosaic of images from U.S. Air Force weather satellites. Much of the light leakage to space corresponds to street and building lights in urbanized regions, especially in Europe, North America and eastern Asia. Also nicely etched are transportation features such as the Trans-Siberian railroad, the main railroad through central China, the spoke pattern centered on the hub of Moscow, and Interstate Highway 5 along the western coast of the United States. The delimiting effects of geographical features such as the Nile river, the Sahara Desert, the Himalayas, and the Australian Outback are also apparent. In the tropics, the major sources of light are controlled fires - the result of grassland burning, slash-and-burn agriculture, and clearing of forests. The frequency of these fires depends on season, but in the present image they are prominent throughout the highlands of Southeast Asia, the sub-Saharan savannas, and East Africa. Other lights arise from huge burn-offs of natural gas associated with oil wells. Gas flares show clearly in Indonesia, the Tashkent region of the Soviet Union, Siberia, the Middle East, North and West Africa, and northwestern South America. In the Sea of Japan, the large blotch of light emanates from a fishing fleet that hangs multitudes of lights on its boats in order to lure squid and saury to the surface. The only natural source of light is the aurora over Greenland.

Cautionary Notes: This image is based on a mosaic of about forty individual photographs, each which has its own distortions. The individual photos were also taken with a variety of exposures and under varying moonlight. The photos in this mosaic were taken at various times and seasons between 1974-1984.

#36

"Holdridge Life Zone Classification"

What is it?

This is a mapped representation of the Holdridge Life Zone Classification (a broad-scale biogeographical model based on correlations between plant formations and climate). The actual Holdridge Life Zone Classification is a pyramid of hexagons that define specific life zones. Holdridge used three climate parameters to define the occurrence of major plant formations: biotemperature, mean annual precipitation, and a potential evapotranspiration (PET) ratio.

Why do we care?

Scientists use vegetation models such as the Holdridge Life Zone Classification to simulate the effects of climate change on the global distribution of vegetation. Broad-scale biogeographic models such as the Holdridge Life Zone Classification are just one type of ecological models that scientists use to project vegetation distribution. Although these models have significant limitations, simulations of the potential response of vegetation to future climate change are useful for understanding both the magnitude of possible vegetation change and biospheric feedbacks to climate change.

Resource Guide Reference:

#37

"New Zones Using Double CO_2 Computer Modeling By Oregon State University"

What is it?

This is a mapped representation of the output from a General Circulation Model (GCM) developed by scientists at Oregon State University using the Holdridge Life Zone Classification to simulate vegetation re-distribution under double CO_2 scenarios. To better understand future scenarios, scientists link biogeographic models with hydrological and atmospheric general circulation models.

Caution MUST be used in interpreting a display such as this one. These are tools that scientists use to better understand future scenarios and are constantly being refined. There are many limitations in a map such as this one. It is very unlikely that ecosystems will shift as complete units to new locations.

#38

"A Global Scale Examination of Our Planet"

What is it?

A variety of instruments are used in the collection of data relating to global environmental change. They vary from the very sophisticated Earth Orbiting System and space stations to the more simple hot-air balloons. Regardless of the level of technology, they are all tools in acquiring remotely-sensed data that provide us with a better understanding of how our planet functions. Data is also collected on the ground and at sea. The tremendous amounts of data collected are analyzed at universities, federal laboratories, and other research centers.

Why do we care?

To better understand global environmental change, it is essential to document and comprehend how the earth works as a system. The advent of technology has helped us to better understand planetary phenomena on a globally-integrated scale.

Resource Guide Reference:

#39

"The New Environmental Ethic"

What is it?

In the past decade or so, a new environmental ethic is evident within the scientific community, government agencies, and the general public. This new environmental ethic links science, information, education, stewardship, and promotes partnerships in making better decisions for the health of our planet.

Why do we care?

As educators, we are attempting to communicate complex scientific information in an understandable and relevant manner to educate the public on global environmental change. Through education, environmental stewardship can be encouraged and ultimately result in decisions that help resolve environmental concerns.

Resource Guide Reference:

Page VI-3, VI-62

#40

"UNCED - The Rio Declaration"

What is it?

In June, 1992, the world focused its attention on the "Earth Summit", the United Nations Conference of Environment and Development (UNCED), held in Rio de Janeiro, Brazil. Representatives of many countries met to discuss a more sensitive use of the planet's diminishing resources.

Why do we care?

As a result of the "Earth Summit", treaties and agreements were negotiated that focused on balancing sustainable economic development with the protection of the environment. It is only through global cooperation, that policies can be enacted to protect the global environment.

Resource Guide Reference:

Page VI-65

#41

"Predictions of Climate Change"

What is it?

There is a great deal of uncertainty in predicting global environmental change. This slide provides a range of expected effects from the "virtually certain" to "uncertain". It is important to remember, that research is constantly ongoing to bring more certainty to these issues and gain better understanding of how the earth functions as a system.

The text on this slide is self explanatory.

Resource Guide Reference:

Page VI-1, V!-5

#42

"Intergovernmental Panel on Climate Change Scientific Assessment of Climate Change"

What is it?

The International Panel on Climate Change (IPCC) was formed in 1988 from the World Meteorological Organization and the United Nations Environmental Program to assess scientific information on global climate issues and to evaluate the possible environmental, social and economic consequences. The IPCC reports are one of the most highly respected reports of Climate Change issues. Scientists from around the world representing numerous scientific disciplines contribute to the IPPC reports.

The text on this slide is self-explanatory.

Resource Guide Reference:

Page VI-5

#43

"Intergovernmental Panel on Climate Change Scientific Assessment of Climate Change"

What is it?

This slide shows the summary of IPCC Policy-makers in 1990.

The International Panel on Climate Change (IPCC) was formed in 1988 from the World Meteorological Organization and the United Nations Environmental Program to assess scientific information on global climate issues and to evaluate the possible environmental, social and economic consequences. The IPCC reports are one of the most highly respected reports of Climate Change issues. Scientists from around the world representing numerous scientific disciplines contribute to the IPPC reports.

The text on this slide is self-explanatory.

Resource Guide Reference:

Page VI-5

#44

"Environmental Stewardship"

What is it?

To be better stewards of our planet, it is recognized that a global environmental ethic must be developed by each of us. In this slide, Schweitzer and Leopold provide two basic "ethical philosophies" on which to make decisions about the global environment. Peck points out that we need to be aware of individual ethics and differences in order to change our own (and others) behavior.

Resource Guide Reference:

Page VI-67

#45

"Natural Resource Philosophy Continuum"

What is it?

There are different philosophies in how the earth's resources are used and can be viewed as a continuum with varying degrees of emphasis on human consumption use and biosphere maintenance. There are trade-offs among how we embrace these various philosophies.

Utilitarianism: A pure utilitarian is concerned solely with the human use of the earth's resources, irrespective of the wider consequences. Although most people will not readily admit to being a pure utilitarian today, there are recent examples of extreme use and exploitation of our resources, such as former Secretary of the Interior James Watt, who tried to carry out his "Sagebrush Revolution: policies during the Reagan administration in the mid-1980s.

Conservationism: The conservationist is committed to use of the natural resources, but attempts to reconcile it within biological constraints. It is prudent to respect the biosphere and maintain productivity in order to have continued use of the resource. Multiple use of our natural resources is the underlying premise as first proposed by Gifford Pinchot in the early 1900s. Today this philosophy is carried out by the U.S. Forest Service in our national forests, and by the U.S. Army corps of Engineers with our water resources.

Environmentalism: The environmentalist is committed to maintaining the integrity of the biosphere; humankind must not imperil it. Maintenance of humankind's existence is a secondary benefit, and the continuation of humankind's ability to use the biosphere is a tertiary benefit. Such individuals as Aldo Leopold, Garrett Hardin, and Barry Commoner would espouse this philosophy.

Preservationism: The preservationist is committed to protection of the biosphere, and sees that parts of the biosphere are unique in their own way and should have limited human use, irrespective of the possible benefits of that use for humans. This view was aptly expressed by Henry David Thoreau, and today is espoused by such groups as The Wilderness Society.

Resource Guide Reference:

The above information was directly quoted from "The challenge of global change: Developing a global ethic" , page VI-67

#46

"Value Acquisition"

What is it?

According to one researcher (Hunter Lewis) we get our values and perceptions of how we view the world from the following 6 factors:

Authority: Taking someone else's work, having faith in an external authority (e.g. having faith in church or the Bible).

Logic: Subjecting beliefs to the variety of consistency tests that underlie deductive reasoning.

Senses: Gaining direct knowledge through our own five senses.

Emotion: Feeling that something is right: although we do not usually associate feeling with thinking or urging, we actually "think" and "judge" through our emotions all the time.

Intuition: Unconscious thinking that is not emotional.

"Science": a synthetic technique relying on sense experience to collect observable facts; intuition to develop a testable hypothesis about the facts; logic to develop the test (experiment); and sense experience again to complete the test.

Resource Guide Reference:

The above was directly quoted from "Six methods by which we acquire our values", page VI-61.

#41

"Decision-Making"

What is it?

Decision making involves an awareness of the problem, an understanding of the problem, and the action needed to address the problem. Ideally, education will increase awareness and understanding of global environmental concerns and lead to positive actions that promote sound environmental stewardship.

Why do we care?

Awareness and understanding alone will not solve the problem. Individuals and decision-makers need to know what type of actions can make a difference. It is then up to them to decide what actions they may take in their daily lives.

Resource Guide Reference:

Pages VI-67, VI-85

#48

"International Agreements Concerning CFC's"

What is it?

This slide outlines the various international agreements concerning the release of CFCs.

The text is self-explanatory

Resource Guide Reference:

Pages VI-65

#49

"CFC-12 Measured Monthly Means"

What is it?

This slide shows reported monthly means for CFC-12 (parts per trillion) at ground level for several data collection stations around the world.

Why do we care?

It appears that in the past few years, there has been a leveling off of CFC-12 concentrations. This has been attributed to international agreements concerning CFC releases. If this is the case, policy decisions can make a difference in global environmental change.

Resource Guide Reference:

Page VI-35

#50

"CFC-11 Measured Monthly Means"

What is it?

This slide shows reported monthly means for CFC-11 (parts per trillion) at ground level for several data collection stations around the world.

Why do we care?

It appears that in the past few years, there has been a leveling off of CFC-11 concentrations. This has been attributed to international agreements concerning CFC releases. If this is the case, policy decisions can make a difference in global environmental change.

Resource Guide Reference:

Page VI-35

GLOBAL CHANGE EDUCATION
RESOURCE GUIDE

SCRIPTS FOR
COLOR OVERHEAD
TRANSPARENCY MASTERS

#1

"Forecasting Time Scales and Human Impacts"

What is it?

Time scales that vary from hours to centuries are used in forecasting and recording weather and climate. The number of people affected by weather and climatic events also vary on a scale from very local (i.e., a relatively few number of people) to a global perspective (i.e., billions of people being impacted).

Note: "synoptic" is a term meteorologists use to mean "everywhere at the same time."

Why do we care?

We need to extend our thinking about climate from a regional, present-oriented mode to a global, long-term mode. Our present activities can affect climate over the long term and can impact many people beyond our political and geographical boundaries. Understanding and interpreting local weather data and understanding their relationship is a very important first step to understanding larger-scale global climate changes.

Resource Guide Reference:

Pages I-1, I-3, I-5, I-7, I-9

#2

"Sources of Climate and Global Change"

What is it?

Many factors, both natural and anthropogenic (human-made), determine earth's climate and global environmental change.

Why do we care?

"Natural variability" includes natural occurrences in the environment which contribute to climate fluctuations and global change. Natural factors can include, but are not limited to the following.

1. Atmosphere: sun (energy, orbit, tilt, cycles), reflection (albedo), clouds, precipitation, wind, gases (H_2O vapor, CO_2, CH_4), feedbacks, and cycles.
2. Geosphere: geography (mountains, water sources), volcanoes, surface roughness, earth's core heat, feedbacks.
3. Biosphere: living organisms, carbon storage and cycling, evaportranspirations, surface roughness, and feedbacks.
4. Hydrosphere: currents (El Nino), surface roughness, ice sheets, cycles, feedbacks.

"Human activities" includes factors which are a direct result of our activities on the planet. As population increases, there are more people participating in activities that contribute to global environmental change. For example, the burning of fossil fuels (oil, coal, wood) results in waste products (additional greenhouse gases being released) which both pollute the air that we breathe and contribute to an enhanced greenhouse effect. Slash and field burning, deforestation, agriculture, destruction of wetlands, building of cities and industries are examples of land use practices that can impact the environment.

Resource Guide Reference:

Pages I-61, I-9, II-1, II-2

#3

"Climate System"

What is it?

The climate system is a tremendously complex system. It is governed not only by what happens in the atmosphere, but in the oceans, the cryosphere (glaciers, sea ice, and continental ice caps), the geosphere (the earth's solid surface) and the biosphere (living organisms in the oceans and on land). The interactions among these various "spheres" are difficult to predict, not least because their respective processes occur on widely differing time scales. The typical response times of the climate system's various components range from a single day to millennia.

Why do we care?

If we are interested in understanding and predicting changes in global climate, we must examine the relationships among the various components. Much more research is needed to enable scientists to better predict how climate change will come about. We need to better understand the various climate-related processes, particularly those associated with clouds, oceans, and the carbon cycle.

Resource Guide Reference:

The above information was directly quoted from "An Introduction to the Climate System", IUCC, page I-1.

#4

"Great Ocean Conveyor Belt"

What is it?

This is a highly generalized graphic conceptualization of how ocean currents circulate around the globe. The key point is the air-to-sea transfer where cold water sinks to the deep ocean carrying CO2 and depositing it on the ocean floor for long-term storage.

Why do we care?

Deep-ocean currents affect long-term climate variations. Over most of the oceans, surface water is warmer (and less dense) than the water beneath it. This discourages surface water from sinking downwards into the deep ocean. Only in certain regions, notably in the Antarctic and northwest Atlantic Oceans, does a combination of evaporation (which increases the water's salt content) and wintertime cooling make surface water dense enough to sink all the way down. This process of "deep-water formation" is still not fully understood, but it is clearly important. It is the primary mechanism whereby heat and absorbed CO_2 and dissolved carbon in surface water is transported down to the ocean depths, where they may remain for thousands of years. Changes in deep ocean currents may have caused natural climate fluctuations in the past, and their role in storing or releasing "excess" carbon could interact with human-induced climate change in the future.

Resource Guide Reference:

The above information was directly quoted from "An Introduction to the Climate System", IUCC, page I-1.

#5

"Surface Hydrology in Some General Circulation Models"

What is it?

This slide depicts the complexity of information needed in only one small part of a General Circulation Model (GCMs). GCMs are complex mathematical representations of ocean-atmospheric relationships that help to understand global and regional climates. These models are the primary tools used by scientists to explore and understand the current planetary climate, and to predict what future climates might be like.

Why do we care?

To better understand and predict future climate scenarios, it is necessary to consider the complex structure and function of all climate-related processes (including the surface hydrology shown in this slide). This slide gives a general view of how water moves over and away from the earth's surface. Note that vegetation on earth (represented by the tree on the slide) has an important influence on the movement of water to and from the atmosphere. Global changes in the amount and types of vegetation can have an impact on hydrologic circulation and thus on climate and weather patterns.

Resource Guide Reference:

Page VI-23

#6.

"Ocean-Atmosphere Circulation in El Nino Southern Oscillation (ENSO)"

What is it?

Note: This slide does not depict an El Nino Event but simply sets the stage for further discussion.

This a generalization of the ocean-atmosphere circulation in the equatorial zone between South America and Asia. It is in this part of the world that the interconnected set of patterns know as El Nino-Southern Oscillation (ENSO) are found. Taken together, they provide the best known example of how the ocean and atmosphere are interconnected.

Why do we care?

El Nino refers to the linked ocean and atmospheric events, which are characterized by a relaxation of the usually intense westward trade winds. These trade winds "pile up" warm surface water in the western Pacific, exposing cold water on the surface in the eastern Pacific. When the trade winds relax, warm surface waters that have been "piled up" in the western Pacific surge eastward. This creates higher than normal sea-surface temperatures in the eastern Pacific, which can lead to heavy rains and flooding. Coastal and equatorial upwelling of sea water ceases, disrupting cold water fisheries and impacting ecological processes.

The Southern Oscillation is an interannual (year to year) process in which atmospheric pressure increases on one side of the Pacific and decreases on the other, and then reverses. For example, when air pressure is low around Australia, it's high to the east around Tahiti. When the air pressure is high around Australia, it's low around Tahiti. The Southern Oscillation is correlated with major changes in rainfall patterns and wind fields over the tropical Pacific and Indian Oceans, and with temperature fluctuations in southeastern Africa, southwestern Canada, and the southern U.S..

ENSO is part of a huge and complex ocean-atmosphere system that has global impacts. Taken together, they have widespread effects, typically increasing rainfall in South America, but causing draught in much of Africa, South East Asia, and Australia.

Resource Guide Reference: Page I-13

#7

"Normal & El Nino Conditions"

What is it?

This cross-sectional graphic compares normal conditions with El Nino conditions in the equatorial Pacific Ocean.

In a normal year, intense westward winds drive westward equatorial currents that push warm Pacific surface waters steadily to the west and expose colder waters, upwelling from the deeper water column, to the surface in the east.

In an El Nino year, the trade winds relax, allowing a surge of warm water eastward across the Pacific and changing the characteristics of waters in the eastern part of the Pacific Ocean basin.

Why do we care?

The changes associated with El Nino events can lead to heavy rains and flooding in some parts of the world, while causing draught in other parts of the world. In addition, coastal and equatorial upwelling of sea water ceases, disrupting cold water fisheries off the coast of South America and impacting ecological processes.

Resource Guide Reference:

Page I-13

#8

"Atmospheric Water Vapor"

What is it?

This is a computer-enhanced representation comparing the amount of atmospheric water vapor around the equator in the Pacific during a "normal" year to the amount of rainfall during an El Nino event.

Why do we care?

During an El Nino event, there is an increase in atmospheric water vapor in the more western longitudes which indicates warmer water temperatures.

Resource Guide Reference:

Page I-13

#9.

"Atmospheric Particles"

What is it?

This graph illustrates the impact on the atmosphere of particles emitted by volcanoes as a result of eruption during the past two decades.

Why do we care?

Great quantities of dust, ashes, CO2, and sulfur dioxide are released into the atmosphere during a volcanic eruption. This can cause short-term cooling due to blockage of incoming solar radiation. The dust and particles can be carried all around the globe by upper level atmospheric winds, thus impacting climate over a large area for as much as four years after the eruption.

Note: The "nrbs" stands for non-rayleigh back scatter. The "(sr-1)" is the units of per steradian. The data is from a lidar (laser radar) which fires a laser beam in the vertical and then waits for the reflected signal to return. If there is no aerosol the reflected signal is from rayleigh scattering (atomic and molecular scattering in the atmosphere). If there is aerosol overhead then more of the signal is reflected back. This is a qualitative indicator of particles above. The units on the axis means that the total column has been integrated. Usually the lidar signal is inverted into a profile (i.e. aerosol concentration vs height) but in this case the profile has been integrated to get the total.

Resource Guide Reference:

I-62-71

#10

"Global Temperature and Atmospheric Carbon Dioxide"

What is it?

Data from the Vostok Ice-core reveal a correlation between CO_2 concentration in the atmosphere and temperature change over the past 160,000 years.

Why do we care?

Many scientists believe that much can be learned about potential future changes in climate by examining past climatic change. One method to study past climates is through the analysis of glacial ice cores. Ice cores provide information about past atmospheric composition based on tiny samples of air trapped in the glacial ice. Since the early 1970s, French and Soviet scientists have collaborated on research at Vostok in Antarctica to drill and examine the deep ice cores. Studying the Vostok core has shown a positive relationship between increases in CO_2 and warm periods of the earth's past, as well as correlations between ice ages and low amounts of atmospheric CO_2.

In addition to CO_2 levels, other information available from analyses of ice cores includes other greenhouse gases (e.g., methane), dust deposition rates (indicating volcanic activity and changes in the extent of desert regions), solar activity (from beryllium-10 analyses), and the availability of cloud condensation nuclei (from plankton-derived sulfur compounds).

Resource Guide Reference:

Pages I-10, I-41-45

#11

"The Global Greenhouse"

What is it?

This is a graphic representation of the greenhouse effect. The ability of certain trace gases (e.g. water vapor, CO_2, CH_4) to be relatively transparent to incoming visible light from the sun, yet opaque to the energy radiated from the earth is one of the best understood processes in atmospheric sciences (known as the greenhouse effect). About 70% of the sun's energy that enters the atmosphere reaches the earth (about 30% is reflected back into space). Greenhouse gases act as a "blanket" and trap the outgoing heat energy thus warming the earth.

Why do we care?

Many scientists believe that human activity is altering the composition of the atmosphere by increasing the concentration of greenhouse gases. It is important to remember that the greenhouse effect is what keeps earth warm enough to be habitable. The current concern is directed at an ***enhanced*** greenhouse effect, one that would put more heat-absorbing gases into the atmosphere and thereby increase global temperatures. The enhanced greenhouse effect has been linked to human activities that result in increased greenhouse gas emissions. Specific human activities include the burning of fossil fuel, deforestation, building and maintaining rice paddies, and industrial processes and emissions.

Resource Guide Reference:

Page II-13

#12

"How the Greenhouse Effect Works"

What is it?

This a generalized drawing of the greenhouse effect. The ability of certain trace gases (e.g. water vapor, CO_2, CH_4) to be relatively transparent to incoming visible light from the sun, yet opaque to the energy radiated from the earth is one of the best understood processes in atmospheric sciences (known as the greenhouse effect). About 70% of the sun's energy that enters the atmosphere reaches the earth (about 30% is reflected back into space). Greenhouse gases act as a "blanket" and trap the outgoing heat energy thus warming the earth.

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Specific human activities include burning of fossil fuels, deforestation, building and maintaining rice paddies, and industrial processes and emissions.

Resource Guide Reference:

Pages II-1, II-3, II-5

#13

"Global Mean Temperature"

What is it?

This graph shows deviations from a global temperature of 15°C for the period from 1854-1990. Global temperature records exist only for the past century or so. The data available to researchers looking for temperature trends are land-based air temperature measurements and marine air-temperature and sea-surface temperature records. All begin around 1860.

Why do we care?

Much of the warming since 1900 has been concentrated in two periods, the first between 1910 and 1940 and the other since 1975; the five warmest years on record have all been in the 1980s. Almost all of the climate models suggest that the world's average surface temperature ought to have warmed somewhere between 0.4°C and 1°C since pre-industrial times as a result of the greenhouse gases emitted so far. So, it follows, that one of the clearest signs of human-induced climate change would be the detection of such a warming. The graph on this slide does seem to show such a warming trend. However, such data must be interpreted carefully. Natural climate variations must also be taken into account. Unambiguous detection of climate change is likely to be a painfully slow process, involving much more detailed comparison of climate model results with observations.

Resource Guide Reference:

Portions of the above were quoted directly from "Why three hot summers don't mean global warming" (IUCC), page I-5.

Page VI-29

#14

"Global Distribution of Atmospheric Carbon"

What is it?

Three-dimensional representation of the global distribution of atmospheric carbon dioxide.

Why do we care?

Atmosphere carbon dioxide content has risen steadily, and also varies considerably between the Northern and Southern hemispheres. This is due both to greater industrialization in the Northern hemisphere and to greater vegetation coverage. It is the role of vegetation that accounts for the annual peaks and valley in carbon dioxide levels. This has been referred to as the "breathing of the earth. During the summer growing season atmospheric carbon levels drop because plants take up CO2 and store it as plant tissue (wood, leaves). During the winter plants do not take up carbon, and fallen leaves decompose releasing some stored carbon.

The vertical axis measures CO_2 concentrations in parts per million (PPM).

Resource Guide Reference:

Page II-25

#15

"Greenhouse Effect"

What is it?

The inset graph shows the concentration of carbon dioxide in the atmosphere from 1958 to mid-1990, measured at the Mauna Loa Observatory on the Island of Hawaii. The annual changes are due to the respiration of plants in the Northern Hemisphere. This set of measurements, made by Charles Keeling of the Scripps Institution of Oceanography, is the longest continuous record. Since Dr. Keeling began his measurements in the 1950s, average annual CO_2 levels have increased from 315 parts per million (ppm) to over 350 ppm. This trend suggests the amount of CO_2 in the atmosphere will likely continue its increase.

Why do we care?

CO_2 is an important greenhouse gas. If the concentrations of atmospheric CO_2 continue to increase, global temperature could also increase. While the changes are uncertain, many scientists predict that temperature increases would result in changed rainfall patterns, increased severe weather events, and a rise in sea level. The potential impacts of such events could effect agricultural productivity, natural ecosystems, coastal flooding, desertification, and have deleterious effects on human health.

Resource Guide Reference:

Page II-13, II-25

#16

"Changes in Global Atmospheric Composition"

What is it?

According to this graphed data, there is a clear increasing concentration of CO_2, CFCs, and CH_4 in the atmosphere. All of these trace gases have the ability to absorb heat energy and thus warm the earth.

Why do we care?

The recent attention given to the greenhouse effect and global warming is based on the recorded increases in concentrations of some of these trace gases due to human activity.

Anthropogenic Sources:

Carbon dioxide (CO_2) is considered to be the most important greenhouse gas. It arises primarily from the burning of fossil fuels and the burning and clearing of forested land for agricultural purposes.

Chlorofluorocarbons (CFCs) have no natural source: they are produced entirely by human activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

Methane (CH_4) is largely a product of natural biological processes, but their output can be accelerated by human activities. CH_4 is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g. ruminants). The additions from human activities include expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

Resource Guide Reference:

Page II-1, II-5, VI-14-18

#17

"Atmospheric Methane Concentrations"

What is it?

Although relatively stable for most of the past 3000 years, there has been a rapid increase in atmospheric methane concentrations in the past century or so. For a thousand years prior to the industrial revolution, the concentration of methane in the atmosphere was relatively constant. However, as the world's population increased, as the world became more industrialized and as agriculture developed, the abundance of methane has increased markedly. This data was taken from ice cores in Greenland and the South Pole.

Why do we care?

Methane (CH_4) is an important greenhouse gas. As with all of the greenhouse gases, methane has the ability to absorb heat energy and contribute to the warming of the earth. Methane is largely a product of natural biological processes, but their output can be accelerated by human activities. CH_4 is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g. ruminants). The additions from human activities include expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

Resource Guide Reference:

Page II-1, II-5, VI-14-18

#18

"Sources & Composition of Greenhouse Gases"

What is it?

Note: The title of this slide is misleading as there are many more than five greenhouse gases (e.g. the main greenhouse gas is water vapor but is not directly affected by human activity). This slide depicts five important greenhouse gases that are associated with human activity.

Carbon dioxide (CO_2) is considered to be the most important greenhouse gas. It arises primarily from the burning of fossil fuels and the burning and clearing of forested land for agricultural purposes.

Chlorofluorocarbons (CFCs) have no natural source: they are produced entirely by human activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

Methane (CH_4) is largely a product of natural biological processes, but their output can be accelerated by human activities. CH_4 is emitted from the decay of organic matter in waterlogged soils (e.g., wetlands, rice paddies) and from the digestive tracts of grazing animals (e.g. ruminants). The additions from human activities include expansion of rice agriculture, the increased number of livestock, increased number of landfills, and leakage from natural gas pipelines.

Ozone (O_3) found in lower altitudes (not to be confused with O_3 levels in the stratosphere) are the result of gases such as carbon monoxide, the oxides of nitrogen (all found in car exhaust fumes), methane, and other hydrocarbons.

Nitrous Oxide (N_2O) is emitted from coal-burning power plants and can be released from the breakdown of chemical fertilizers in the soil.

The major human activity that is responsible for increased greenhouse gas emissions is the burning of fossil fuel. Other human activities that contribute to increased levels of greenhouse gases are deforestation, industrial processes and agricultural practices.

Resource Guide Reference: Page II-1, II-5, VI 19-22

#19

"Greenhouse Index: Countries with Highest Greenhouse Gas Emissions, 1989"

What is it?

This bar graph shows which countries are responsible for the highest level of greenhouse gas emissions (1989).

Why do we care?

From this graphic, it is clear that the industrialized nations had the highest percentage of total global greenhouse gas emissions. in 1989.

Resource Guide Reference:

#20

"World Population Growth, 900 AD - 1990 AD"

What is it?

Human population is growing exponentially, and is a primary driving force in the increase of greenhouse gases in the atmosphere and other environmental concerns both locally and globally.

Why do we care?

World population in 1994 is approximately 5.6 - 5.7 billion and growing at over 94 million people per year.

At current growth rates our population will double in less than 50 years.

Population and resource use patterns must be considered in tandem. While most of the growth in sheer human numbers is occurring in the developing world, industrialized countries consume a far greater percentage of the world's resources.

Resource Guide Reference:

#21

"Projected Population of the World, 1990 - 2150"

What is it?

Decisions we make in the next few years will have a tremendous effect on the growth of human population and therefore on our impact on the global environment.

Why do we care?

These varying scenarios will be the result of differing policy decisions. Human population growth is a very sensitive issue with many cultural and religious implications and responses.

Resource Guide Reference:

#22

"Distribution of Tropical Forests"

What is it?

The highlighted area in this slide shows the distribution of tropical forests. The inset bar graph represents the extent of tropical deforestation cleared annually (in millions of acres) It is important to review the inset note that explains changes in deforestation rates since the publication of this graphic.

Why do we care?

Tropical forests are richer in species than any other terrestrial habitat. Closed tropical forests contain at least 50 percent and perhaps 90 percent of the world's species, although they cover only 7 percent of the earth's land surface. They include two thirds of the worlds vascular plant species and about 30 percent of its terrestrial vertebrate species. Up to 96 percent of the world's arthropods may be found in tropical forests. The destruction of tropical forests has pushed many species into extinction.

Tropical forests are important not only as the home to myriad plant and animal species, and as the source of valuable products, but also because they support diverse human cultures. Tropical forests also regulate vital biological, geological, and chemical cycles.

Tropical forests have been referred to as the earth's "lungs". The profuse biomass found in tropical forests removes enormous quantities of CO_2 from the atmosphere through photosynthesis acting as a carbon "sink". Through the common practice of slash-burning the forest to make way for agricultural lands, the stored carbon is released back into the atmosphere, adding to the concentration of atmospheric CO_2.

Resource Guide Reference:

Portions of the above text were directly quoted from "Status of Selected Habitats", World Resource Institute, page V-21

#23

"Future Greenhouse Gas Trends Under Double CO_2 Conditions"

What is it?

Note: This title may be confusing in that CO_2 is a greenhouse gas. Climate simulations using General Circulation Models (such as the Goddard Institute for Space Studies (GISS) model used for this projection) suggest that the production of greenhouse gases (e.g. carbon dioxide, nitrous oxide, methane, and CFCs) from anthropogenic activities could cause changes in the global climate. GCMs of the earth's atmosphere are a tool that scientists use in making quantitative estimates of climate variables such as temperature and precipitation. GCMs have been used to simulate the possible effect on global climate given a doubling of CO_2 concentrations.

This bar graph shows greenhouse gas concentrations from the 1950s to the 1980s and projected concentrations though the 2020s. The Y axis depicts temperature change in degrees Fahrenheit.

Why do we care?

From this graphic, it is clear that an increase in greenhouse gas concentrations are closely associated with a rise in global temperature. It is important to remember that GCMs are scientific tools - not crystal balls - and there is a great deal of uncertainty in the output of GCMs. However, most scientists agree that continued greenhouse gas emissions could result in a warmer earth.

According to the IPCC report, "We calculate with confidence that atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide, and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for the centuries ahead. The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations to stabilize at a given level. The long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's level; methane would require a 15-20% reduction."

Resource Guide Reference: Pages VI-1, VI-7

#24

"Causes of Relative Sea Level (RSL) Change"

What is it?

There are two primary causes of changes in sea level:

Vertical Land Movement

a) isostatic adjustment - changes in the level of the land
b) tectonic effects - the surface of the earth is divided into plates which are in constant motion, bumping into or slipping over or under each other
c) sedimentation - sediments are washed to the coast via run-off into rivers and streams, melting of ice-sheets and glaciers.
d) human factors - groundwater and oil extraction (example - In Los Angeles, land is being lowered due to oil extraction, resulting in sea level rise.

Changes in the Level of the Ocean's Surface

a) more water enters the oceans via melting glaciers and ice sheets
b) ocean currents and tides
c) changes in the water cycle
d) expansion of the water itself due to warming (or contraction, if the climate cools and ice sheets extend).

Why do we care?

An accelerated rise in sea level would inundate coastal wetlands and lowlands, increase the rate of shoreline erosion, exacerbate coastal flooding, raise water tables, threaten coastal structures, and increase the salinity of rivers, bays, and aquifers.

Resource Guide Reference:

Pages III-1, III-3, III-7, VI 30-32

#25

"Factors Projected to Contribute to Sea Level Rise from 1985 to 2030"

What is it?

This slide represents factors that could contribute to sea level rise in the future. Over the past 100 years, sea level has risen 10 - 20 centimeters. Scientists are now predicting that in the next 50 years the rate will double.

Why do we care?

This projected doubling is attributed to the following:
Thermal expansion (in oceanic thermal expansion, as the water molecules are warmed, the volume of water increases) would account for most of the projected sea level rise if global temperatures increase as predicted. Mountain glaciers would account for 49% of the sea level rise, whereas in the past 100 years melting has accounted for only a small portion of the rise in sea level. The melting of the Greenland ice cap would contribute about 12% of the increase. It is interesting to note that the Antarctic might even cause sea level to fall. Some scientists are now predicting that as the temperature warms and there is more moisture in the atmosphere, there will be more snow at the poles, therefore more cooling at the poles and a projected decrease melting (this accounts for the negative value attributed to the Antarctica ice shield).

Floating ice caps (e.g. those found in the Arctic Ocean) are not expected to have an impact on sea level because this ice is already floating, thus displacing its volume in the water.

Resource Guide Reference:

Pages III-3, III-13, VI 30-32

#26

"Atmospheric CO_2 and Sea Level Rise"

What is it?

Global Mean Sea Level from 1881 to 1980 has generally paralleled the rise in atmospheric CO_2. If the CO_2 concentration continues to rise at the present rate and if rising sea levels continue to parallel that trend, sea level is projected to rise at a rate of 50 centimeters per 100 years rather than the 20-20 centimeters that has been recorded in the last 100 years.

Why do we care?

Higher sea levels threaten low-lying coastal areas and island countries. Bangladesh and the Maldives Islands are examples of lands that would be at terrible risk for loss of life, homes, and businesses. Groundwaters are already becoming saline in some locations through salt water intrusion that accompanies subsidence. Estuarine habitats would be changed with a greater influx of salt water and intertidal communities would be moved to high elevation where they would have to compete with development. Damage due to floods would be more severe in the coastal areas where much of the world's population will be located in the next century. Economic and habitat loss for humans as well as plant and animal species would be extensive.

Resource Guide Reference:

Pages III-3, III-7

#27

"Sea-Level Rise Scenarios"

What is it?

This graph shows the sea level rise expected from 1900-2100 under a "business as usual scenario" emissions (no cutting back on human-induced emissions). Shown is the best estimate and range. The high estimate indicates that we could have an average rise globally of a little more than a meter; the low estimate indicates about another 20 - 20 centimeter rise (much like that of the past 100 years). There will be significant regional variations.

Why do we care?

As with most projections, there is a great deal of uncertainty in what will actually happen. snow level accumulation in Antarctica could moderate the net sea level rise. Sea level will rise at different rates in different parts of the world due to local coastline variations, changes in ocean currents, regional land subsidence and emergence, and differences in tides and water density.

Resource Guide Reference:

Page VI-30

#28

"The Ozone Layer"

What is it?

Ozone is a form of oxygen. In the lower atmosphere, oxygen is usually found in molecules composed of two atoms of oxygen. This molecule, abbreviated O_2, is the common form of oxygen that we need to breathe. Ozone is a more unstable and uncommon molecule made up of three oxygen atoms and is abbreviated O_3. The Ozone layer is found in the stratosphere between 15 and 25 miles above the Earth's surface.

Why do we care?

The Ozone Layer acts as a protective screen, filtering out the sun's harmful ultraviolet (UV-B) rays. Life on Earth as we know it has evolved to depend on this screen, and many life forms could be severely affected is this protective screen is significantly weakened.

Although ozone is a greenhouse gas, the destruction of the ozone layer is a different atmospheric phenomena than concerns a possible enhanced greenhouse effect. In this slide, the Ozone Layer screens out much of the incoming UV-B radiation, while the visible light penetrates through and is absorbed by Earth. Much of this infrared radiation is trapped in the lower atmosphere by the greenhouse gases and is responsible for the Earth being warm enough to sustain life as we know it.

Resource Guide Reference:

Portions of the above text were taken from "The Hole Story" UNH

Page IV-1, IV-9

#29

"How is Ozone Destroyed?"

What is it?

Ozone depletion is a cyclical process. This slide shows the journey of a chlorine atom released from a CFC molecule and its destructive path in the upper atmosphere. Each chlorine atom from a CFC molecule has the potential to destroy tens of thousands of ozone molecules.

Why do we care?

In the natural functioning of the atmosphere, the creation and destruction of ozone occurs in equilibrium. In recent decades, human activity and the release of chemical compounds that find their way into the upper atmosphere have disrupted the natural equilibrium. Specifically, the release of compounds containing chlorine and bromine are attacking the ozone layer. The most common of these human-generated compounds are chloroflourcarbons (CFCs) and bromoflourocarbons (halons). Because of their stable chemical structure, these compounds don't break down in the lower atmosphere. They take five to ten years to reach the stratosphere, where they are broken down by intense UV radiation. This breakdown releases atoms of chlorine (from CFCs) or bromine (from halons) that react with and destroy ozone. At certain times of the year and over certain parts of the globe, ozone in the stratosphere is being destroyed slightly faster than it is being created.

Resource Guide Reference:

Portions of this text were taken from "The Hole Story", UNH

Pages IV-1, IV-9

#30

"Ozone Depletion"

What is it?

This sequence of color-coded images shows the decline in the amount of ozone in the upper atmosphere over Antarctica (the expanding black spot represents ozone value; the larger the spot, the less ozone found in the stratosphere) in October from 1980 to 1992.

Why do we care?

World-wide attention was given to the "discovery" of the "ozone hole" over Antarctica in the early 1980s. This highly publicized atmospheric phenomena is observed annually each October during the Antarctic spring. After several weeks, the Antarctic vortex, a whirling weather system that encircles and isolates the South Pole during winter, breaks up, and ozone levels rapidly rise. In meteorological terms, the Antarctic ozone hole is a significant ozone minimum and not a literal "hole" through the ozone layer. Nevertheless, for a brief time ozone levels within the hole can plummet to 150DU or even lower.

Resource Guide Reference:

Page IV-1, IV-9

#31

"Production and Uses of CFC Gases"

What is it?

This slide depicts the production and uses of CFC gases from 1960 to 1988. Chlorofluorocarbons (CFCs) are a category of gases that include molecules of chlorine, flourine, carbon, and bromine. CFCs have no natural source: they are produced entirely by human activity. CFCs are used widely as refrigerants in air conditioners, refrigerators, freezers, and heat pumps. They are found in some foam plastics and used in some electronics manufacturing.

Why do we care?

CFC production and use has been heavily influenced in the last 20 years by scientific research and subsequent policy decisions. In the mid-1970s (left bar graph), the largest application of CFCs was found as propellants in aerosol sprays. The use of CFCs in aerosols was banned in the United States and several other countries in 1978, which led to a temporary drop in CFC production. However, other uses of CFCs were rapidly expanded, including refrigeration, foam blowing, and solvent applications which led to a large overall increase in CFC production throughout the 1980s.

Since the passage of the Montreal Protocol and its London and Copenhagen Amendments, CFC production has decreased by over 50%. As a result of this, scientists are beginning to detect a leveling off of CFC concentration in the atmosphere.

Resource Guide Reference:

Pages IV-1, IV-9, VI-14 - VI-21

#32

"Marine Ecosystem Food Web"

What is it?

This slide provides a generalized example of the biological food web in a marine ecosystem. The biological food web in marine ecosystems starts will the primary producers - mainly the phytoplankton. Primary consumers utilize the biomass the phytoplankton produce, and are themselves food input for the next level in the food web. Because of their need for the sun's energy, phytoplankton are restricted to the upper layers of their oceanic environment. Mutual shading, absorption, and light scattering prevent effective light penetration below a certain depth where phytoplankton cannot survive.

Why do we care?

Climate change implications:

Climate change will affect phytoplankton, and vice versa. Warmer temperatures may benefit some species and hurt others. Changes in CO_2 levels may not have a direct impact, but related "feedback loops" could be important. For example, because plankton create a chemical substance called dimethysulfide (DMS) that may promote the formation of clouds over the oceans, changes in plankton population could lead to changes in cloudiness. At the same time, more clouds would reduce the amount of solar radiation reaching the oceans, which could reduce plankton activity.

Increased UV penetration implications:

The depletion of the ozone layer by CFCs would increase the amount of ultraviolet light reaching the ocean surface, which could have negative effects on the plankton. Ultraviolet radiation damage to the primary producers will have dramatic consequences because these organisms produce more than one-half of the earth's biomass.

Resource Guide Reference:

The above information was directly quoted from "Oceans and the carbon cycle" page V-3 and "Aquatic ecosystems", page V-7

#33

"Coastal Population by 2010 in Continental U.S."

What is it?

This slide projects the portion of U.S. population living in coastal areas by 2010 compared with the total U.S. land area. Although coastal areas account for only a small portion of total U.S. land area, almost half of the U.S. population is projected to be living in coastal areas by 2010. It is expected that coastal areas will have 394 persons per square mile as compared to 95 persons per square mile for the rest of the U.S. land area.

Why do we care?

The coastal areas may be hit with a "double-whammy", that is, increased pressure from population growth and development, and from changes associated with sea level rise. Even without the implications of sea level rise, coastal areas in this country are heavily impacted by population and subsequent development pressures. Shoreline erosion, loss of wetlands, salt water intrusion, loss of important wildlife habitat, pollution, and changes in upland areas are all a result of increased development in coastal areas.

Resource Guide Reference:

Page III-7, V-23

#34

"Plankton Production"

What is it?

The darker green areas on this slide represent areas with high plankton productivity.

Why do we care?

Planktonic marine organisms account for over one-half of the total, global amount of annual fixed carbon. Any reduction in this productivity will undoubtedly affect the global food supply and global climate.

Resource Guide Reference:

Page V-11

#35

"Earth at Night"

What is it?

Text taken directly from the Earth at Night" poster:

A tapestry of city lights and rural fires announces our presence on this planet. In contrast to daytime images, where only natural features are easily visible, the activities of humankind at night are readily traced in this mosaic of images from U.S. Air Force weather satellites. Much of the light leakage to space corresponds to street and building lights in urbanized regions, especially in Europe, North America and eastern Asia. Also nicely etched are transportation features such as the Trans-Siberian railroad, the main railroad through central China, the spoke pattern centered on the hub of Moscow, and Interstate Highway 5 along the western coast of the United States. The delimiting effects of geographical features such as the Nile river, the Sahara Desert, the Himalayas, and the Australian Outback are also apparent. In the tropics, the major sources of light are controlled fires - the result of grassland burning, slash-and-burn agriculture, and clearing of forests. The frequency of these fires depends on season, but in the present image they are prominent throughout the highlands of Southeast Asia, the sub-Saharan savannas, and East Africa. Other lights arise from huge burn-offs of natural gas associated with oil wells. Gas flares show clearly in Indonesia, the Tashkent region of the Soviet Union, Siberia, the Middle East, North and West Africa, and northwestern South America. In the Sea of Japan, the large blotch of light emanates from a fishing fleet that hangs multitudes of lights on its boats in order to lure squid and saury to the surface. The only natural source of light is the aurora over Greenland.

Cautionary Notes: This image is based on a mosaic of about forty individual photographs, each which has its own distortions. The individual photos were also taken with a variety of exposures and under varying moonlight. The photos in this mosaic were taken at various times and seasons between 1974-1984.

#36

"Holdridge Life Zone Classification"

What is it?

This is a mapped representation of the Holdridge Life Zone Classification (a broad-scale biogeographical model based on correlations between plant formations and climate). The actual Holdridge Life Zone Classification is a pyramid of hexagons that define specific life zones. Holdridge used three climate parameters to define the occurrence of major plant formations: biotemperature, mean annual precipitation, and a potential evapotranspiration (PET) ratio.

Why do we care?

Scientists use vegetation models such as the Holdridge Life Zone Classification to simulate the effects of climate change on the global distribution of vegetation. Broad-scale biogeographic models such as the Holdridge Life Zone Classification are just one type of ecological models that scientists use to project vegetation distribution. Although these models have significant limitations, simulations of the potential response of vegetation to future climate change are useful for understanding both the magnitude of possible vegetation change and biospheric feedbacks to climate change.

Resource Guide Reference:

#31

"New Zones Using Double CO_2 Computer Modeling By Oregon State University"

What is it?

This is a mapped representation of the output from a General Circulation Model (GCM) developed by scientists at Oregon State University using the Holdridge Life Zone Classification to simulate vegetation re-distribution under double CO_2 scenarios. To better understand future scenarios, scientists link biogeographic models with hydrological and atmospheric general circulation models.

Caution MUST be used in interpreting a display such as this one. These are tools that scientists use to better understand future scenarios and are constantly being refined. There are many limitations in a map such as this one. It is very unlikely that ecosystems will shift as complete units to new locations.

#38

"A Global Scale Examination of Our Planet"

What is it?

A variety of instruments are used in the collection of data relating to global environmental change. They vary from the very sophisticated Earth Orbiting System and space stations to the more simple hot-air balloons. Regardless of the level of technology, they are all tools in acquiring remotely-sensed data that provide us with a better understanding of how our planet functions. Data is also collected on the ground and at sea. The tremendous amounts of data collected are analyzed at universities, federal laboratories, and other research centers.

Why do we care?

To better understand global environmental change, it is essential to document and comprehend how the earth works as a system. The advent of technology has helped us to better understand planetary phenomena on a globally-integrated scale.

Resource Guide Reference:

#39

"The New Environmental Ethic"

What is it?

In the past decade or so, a new environmental ethic is evident within the scientific community, government agencies, and the general public. This new environmental ethic links science, information, education, stewardship, and promotes partnerships in making better decisions for the health of our planet.

Why do we care?

As educators, we are attempting to communicate complex scientific information in an understandable and relevant manner to educate the public on global environmental change. Through education, environmental stewardship can be encouraged and ultimately result in decisions that help resolve environmental concerns.

Resource Guide Reference:

Page VI-3, VI-62

#40

"UNCED - The Rio Declaration"

What is it?

In June, 1992, the world focused its attention on the "Earth Summit", the United Nations Conference of Environment and Development (UNCED), held in Rio de Janeiro, Brazil. Representatives of many countries met to discuss a more sensitive use of the planet's diminishing resources.

Why do we care?

As a result of the "Earth Summit", treaties and agreements were negotiated that focused on balancing sustainable economic development with the protection of the environment. It is only through global cooperation, that policies can be enacted to protect the global environment.

Resource Guide Reference:

Page VI-65

#41

"Predictions of Climate Change"

What is it?

There is a great deal of uncertainty in predicting global environmental change. This slide provides a range of expected effects from the "virtually certain" to "uncertain". It is important to remember, that research is constantly ongoing to bring more certainty to these issues and gain better understanding of how the earth functions as a system.

The text on this slide is self explanatory.

Resource Guide Reference:

Page VI-1, V!-5

#42

"Intergovernmental Panel on Climate Change Scientific Assessment of Climate Change"

What is it?

The International Panel on Climate Change (IPCC) was formed in 1988 from the World Meteorological Organization and the United Nations Environmental Program to assess scientific information on global climate issues and to evaluate the possible environmental, social and economic consequences. The IPCC reports are one of the most highly respected reports of Climate Change issues. Scientists from around the world representing numerous scientific disciplines contribute to the IPPC reports.

The text on this slide is self-explanatory.

Resource Guide Reference:

Page VI-5

#43

"Intergovernmental Panel on Climate Change Scientific Assessment of Climate Change"

What is it?

This slide shows the summary of IPCC Policy-makers in 1990.

The International Panel on Climate Change (IPCC) was formed in 1988 from the World Meteorological Organization and the United Nations Environmental Program to assess scientific information on global climate issues and to evaluate the possible environmental, social and economic consequences. The IPCC reports are one of the most highly respected reports of Climate Change issues. Scientists from around the world representing numerous scientific disciplines contribute to the IPPC reports.

The text on this slide is self-explanatory.

Resource Guide Reference:

Page VI-5

#44

"Environmental Stewardship"

What is it?

To be better stewards of our planet, it is recognized that a global environmental ethic must be developed by each of us. In this slide, Schweitzer and Leopold provide two basic "ethical philosophies" on which to make decisions about the global environment. Peck points out that we need to be aware of individual ethics and differences in order to change our own (and others) behavior.

Resource Guide Reference:

Page VI-67

#45

"Natural Resource Philosophy Continuum"

What is it?

There are different philosophies in how the earth's resources are used and can be viewed as a continuum with varying degrees of emphasis on human consumption use and biosphere maintenance. There are trade-offs among how we embrace these various philosophies.

Utilitarianism: A pure utilitarian is concerned solely with the human use of the earth's resources, irrespective of the wider consequences. Although most people will not readily admit to being a pure utilitarian today, there are recent examples of extreme use and exploitation of our resources, such as former Secretary of the Interior James Watt, who tried to carry out his "Sagebrush Revolution: policies during the Reagan administration in the mid-1980s.

Conservationism: The conservationist is committed to use of the natural resources, but attempts to reconcile it within biological constraints. It is prudent to respect the biosphere and maintain productivity in order to have continued use of the resource. Multiple use of our natural resources is the underlying premise as first proposed by Gifford Pinchot in the early 1900s. Today this philosophy is carried out by the U.S. Forest Service in our national forests, and by the U.S. Army corps of Engineers with our water resources.

Environmentalism: The environmentalist is committed to maintaining the integrity of the biosphere; humankind must not imperil it. Maintenance of humankind's existence is a secondary benefit, and the continuation of humankind's ability to use the biosphere is a tertiary benefit. Such individuals as Aldo Leopold, Garrett Hardin, and Barry Commoner would espouse this philosophy.

Preservationism: The preservationist is committed to protection of the biosphere, and sees that parts of the biosphere are unique in their own way and should have limited human use, irrespective of the possible benefits of that use for humans. This view was aptly expressed by Henry David Thoreau, and today is espoused by such groups as The Wilderness Society.

Resource Guide Reference:

The above information was directly quoted from "The challenge of global change: Developing a global ethic" , page VI-67

#46

"Value Acquisition"

What is it?

According to one researcher (Hunter Lewis) we get our values and perceptions of how we view the world from the following 6 factors:

Authority: Taking someone else's work, having faith in an external authority (e.g. having faith in church or the Bible).

Logic: Subjecting beliefs to the variety of consistency tests that underlie deductive reasoning.

Senses: Gaining direct knowledge through our own five senses.

Emotion: Feeling that something is right: although we do not usually associate feeling with thinking or urging, we actually "think" and "judge" through our emotions all the time.

Intuition: Unconscious thinking that is not emotional.

"Science": a synthetic technique relying on sense experience to collect observable facts; intuition to develop a testable hypothesis about the facts; logic to develop the test (experiment); and sense experience again to complete the test.

Resource Guide Reference:

The above was directly quoted from "Six methods by which we acquire our values", page VI-61.

#41

"Decision-Making"

What is it?

Decision making involves an awareness of the problem, an understanding of the problem, and the action needed to address the problem. Ideally, education will increase awareness and understanding of global environmental concerns and lead to positive actions that promote sound environmental stewardship.

Why do we care?

Awareness and understanding alone will not solve the problem. Individuals and decision-makers need to know what type of actions can make a difference. It is then up to them to decide what actions they may take in their daily lives.

Resource Guide Reference:

Pages VI-67, VI-85

#48

"International Agreements Concerning CFC's"

What is it?

This slide outlines the various international agreements concerning the release of CFCs.

The text is self-explanatory

Resource Guide Reference:

Pages VI-65

#49

"CFC-12 Measured Monthly Means"

What is it?

This slide shows reported monthly means for CFC-12 (parts per trillion) at ground level for several data collection stations around the world.

Why do we care?

It appears that in the past few years, there has been a leveling off of CFC-12 concentrations. This has been attributed to international agreements concerning CFC releases. If this is the case, policy decisions can make a difference in global environmental change.

Resource Guide Reference:

Page VI-35

#50

"CFC-11 Measured Monthly Means"

What is it?

This slide shows reported monthly means for CFC-11 (parts per trillion) at ground level for several data collection stations around the world.

Why do we care?

It appears that in the past few years, there has been a leveling off of CFC-11 concentrations. This has been attributed to international agreements concerning CFC releases. If this is the case, policy decisions can make a difference in global environmental change.

Resource Guide Reference:

Page VI-35

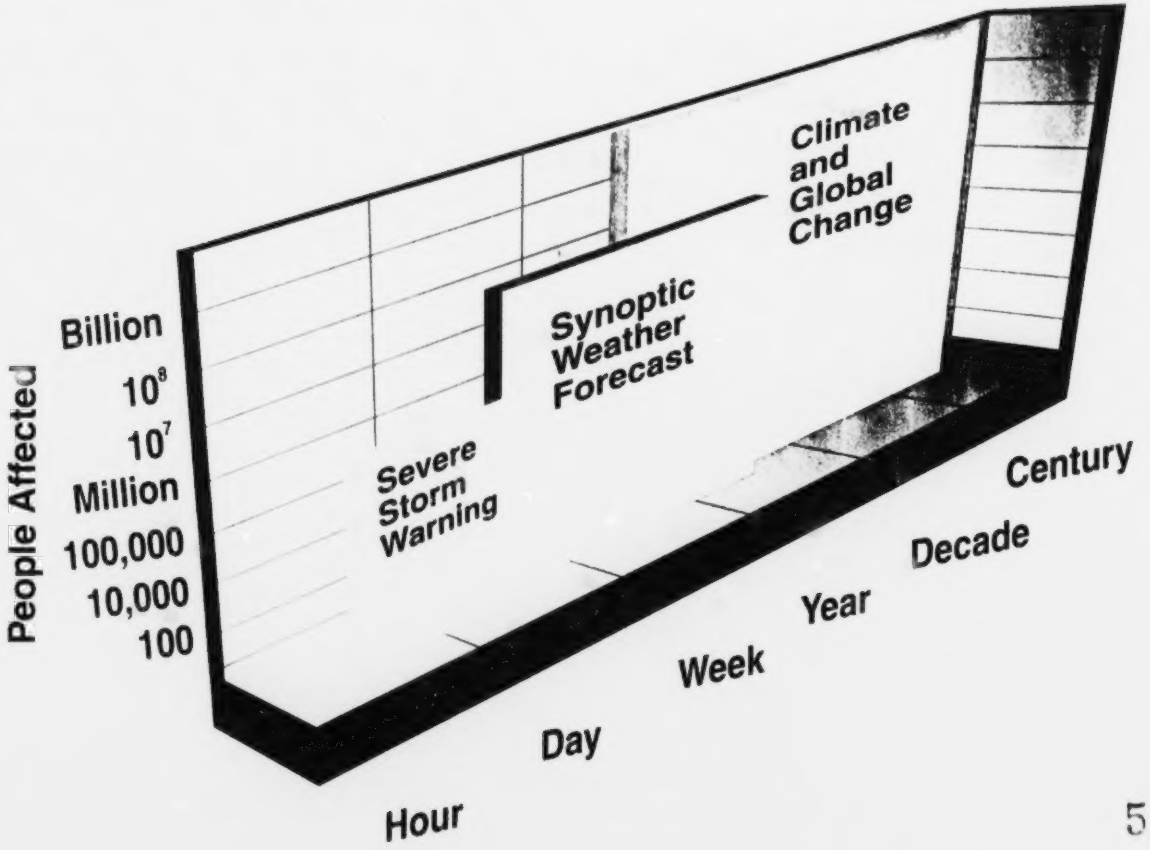
GLOBAL CHANGE

OVERHEAD TRANSPARENCY

MASTERS

NOTE: TO TRANSFER TO CLEAR OVERHEAD ACETATE FOR COLOR TRANSPARENCIES, UTILIZE A SHORT ORDER PRINTING COMPANY OR A 24-HOUR PRINTING SERVICE. DO NOT USE A THERMALFAX MACHINE.

FORECASTING TIME SCALES AND HUMAN IMPACTS



SOURCES OF CLIMATE AND GLOBAL CHANGE

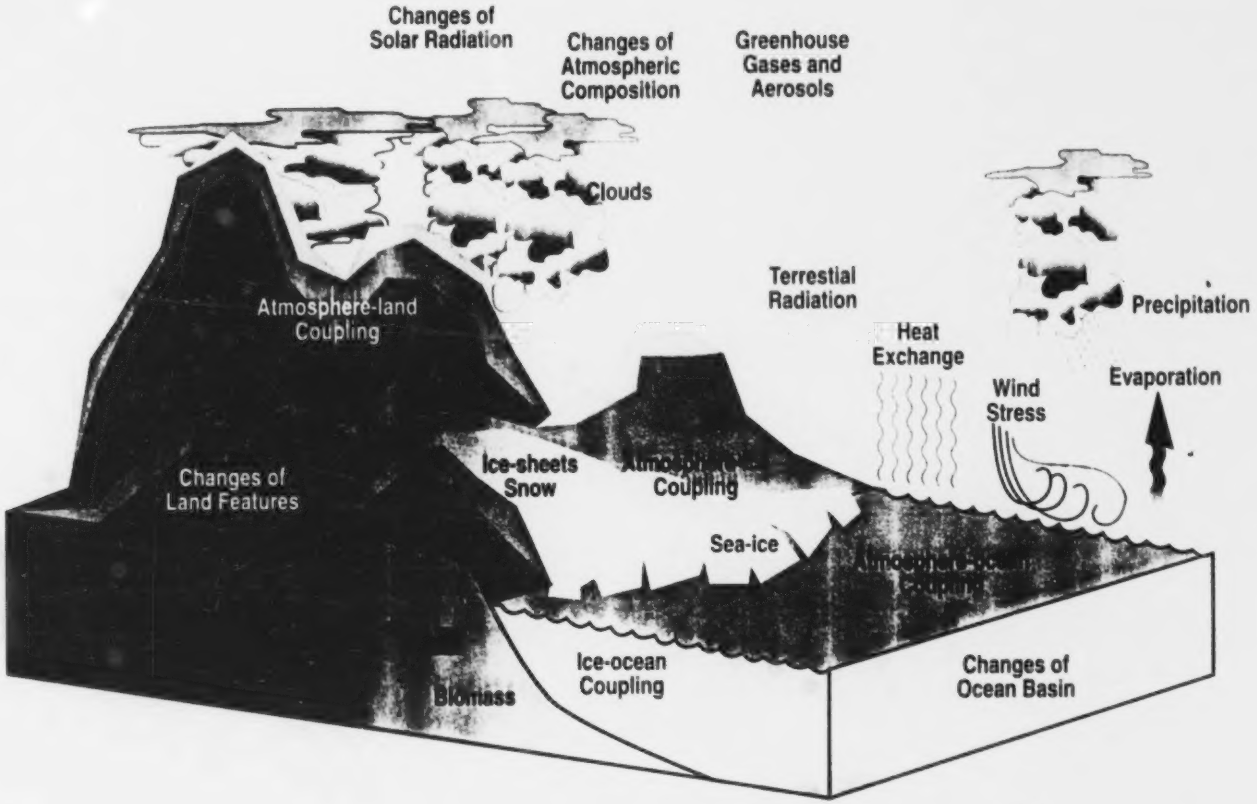
NATURAL VARIABILITY

- Solar Variability
- Volcanic Activity
- Biological Evolution
- El Niño Southern Oscillation (ENSO)

HUMAN ACTIVITIES

- Population Growth
- Energy Usage
- Land Practices
- Industrial Activity

CLIMATE SYSTEM


Changes of Solar Radiation
Changes of Atmospheric Composition
Greenhouse Gases and Aerosols
Clouds
Terrestial Radiation
Precipitation
Atmosphere-land Coupling
Heat Exchange
Evaporation
Wind Stress
Ice-sheets Snow
Atmosphere-ice Coupling
Changes of Land Features
Sea-ice
Atmosphere-ocean Coupling
Ice-ocean Coupling
Biomass
Changes of Ocean Basin

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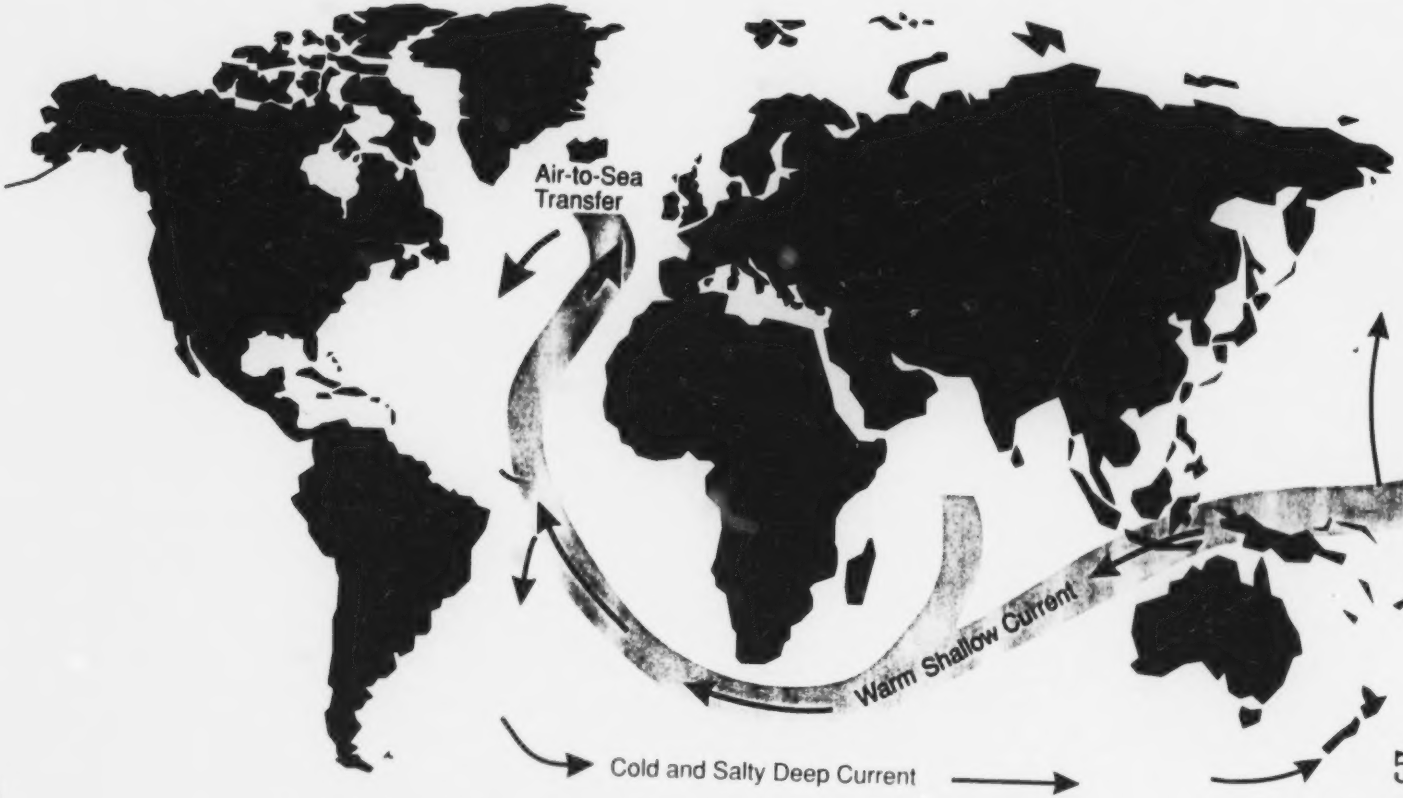
GREAT OCEAN CONVEYOR BELT


Air-to-Sea Transfer
Warm Shallow Current
Cold and Salty Deep Current

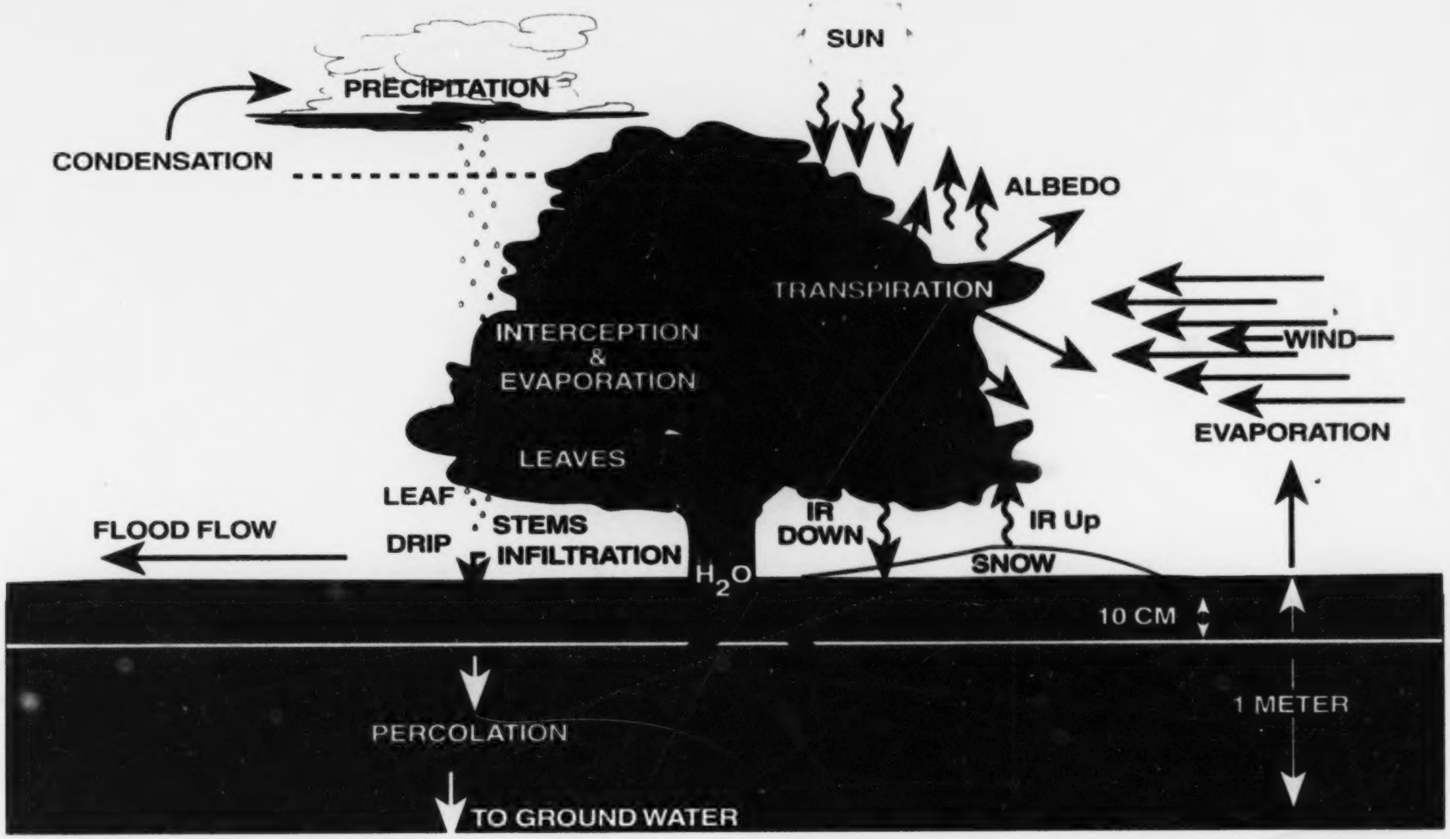
523

524

All the oceans of the world are interconnected through circulation. Keypoint is air-to-sea transfer where cold water sinks to deep ocean carrying CO_2 and depositing on ocean floor.

Source Broecker, W.S., *The Biggest Chill*, Natural History Magazine, pp.47-82, Oct.1987.

SURFACE HYDROLOGY IN SOME GENERAL CIRCULATON MODELS

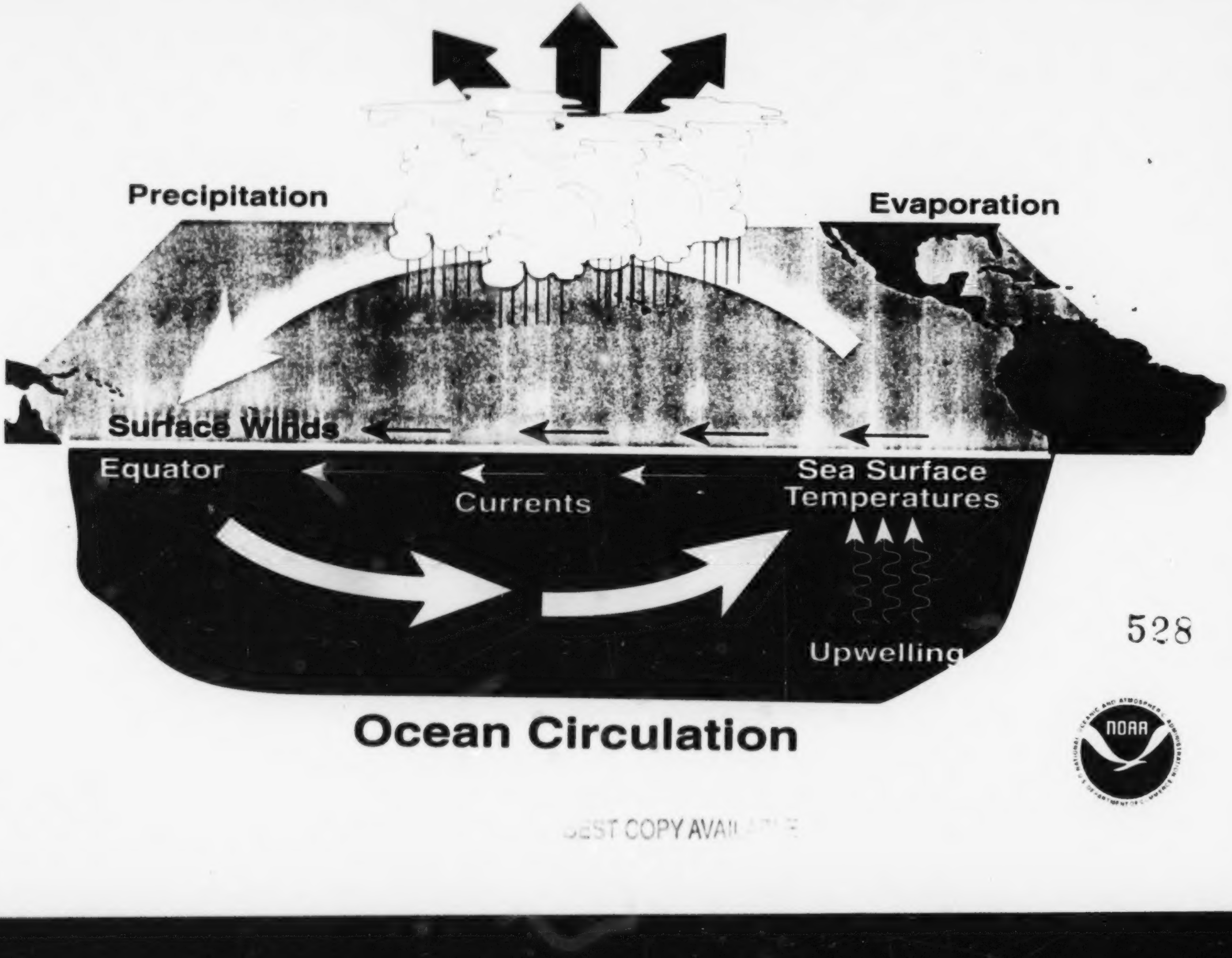

SUN
PRECIPITATION
CONDENSATION
ALBEDO
TRANSPIRATION
WIND
INTERCEPTION
&
EVAPORATION
EVAPORATION
LEAVES
LEAF
DRIP
STEMS
INFILTRATION
FLOOD FLOW
IR
DOWN
IR Up
SNOW
H_2O
10 CM
1 METER
PERCOLATION
TO GROUND WATER

Note: IR= Infrared Radiation

BEST COPY AVAILABLE

OCEAN - ATMOSPHERE CIRCULATION IN EL NIÑO SOUTHERN OSCILLATION (ENSO)

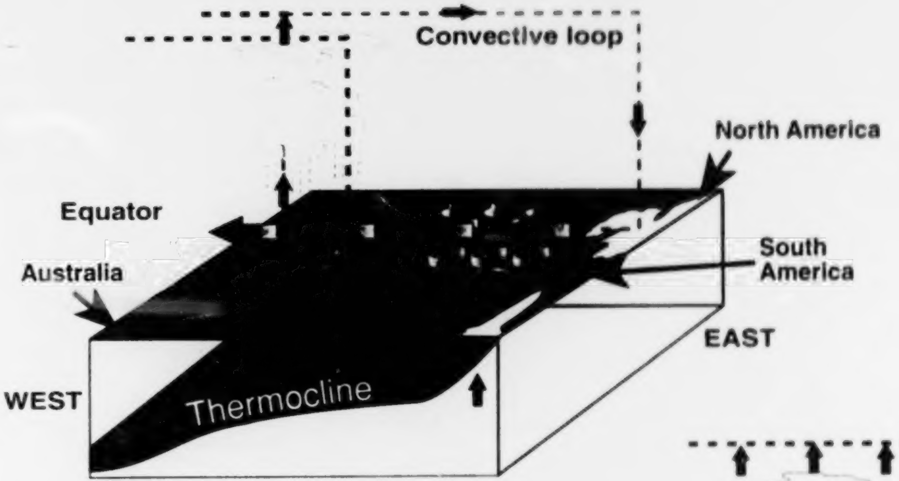
Atmospheric Circulation


Precipitation
Evaporation
Surface Winds
Equator
Currents
Sea Surface Temperatures
Upwelling

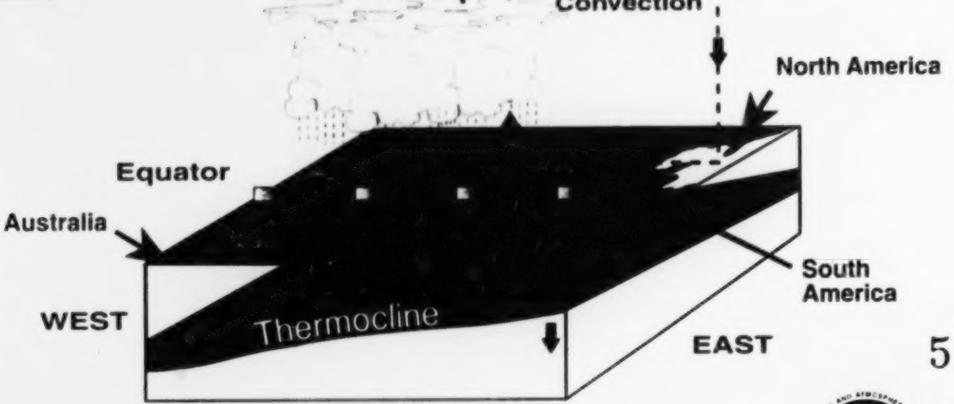
Ocean Circulation

BEST COPY AVAILABLE

NORMAL & EL NIÑO CONDITIONS


Convective loop
North America
Equator
South America
Australia
EAST
WEST
Thermocline

Normal Conditions


Increased Convection
North America
Equator
Australia
South America
WEST
Thermocline
EAST

El Niño Conditions

Source: Jayne Doucette, Woods Hole Oceanographic Institute Graphics, In *Oceanus*, "El Niño," Vol. 35, No.2., Summer, 1992.

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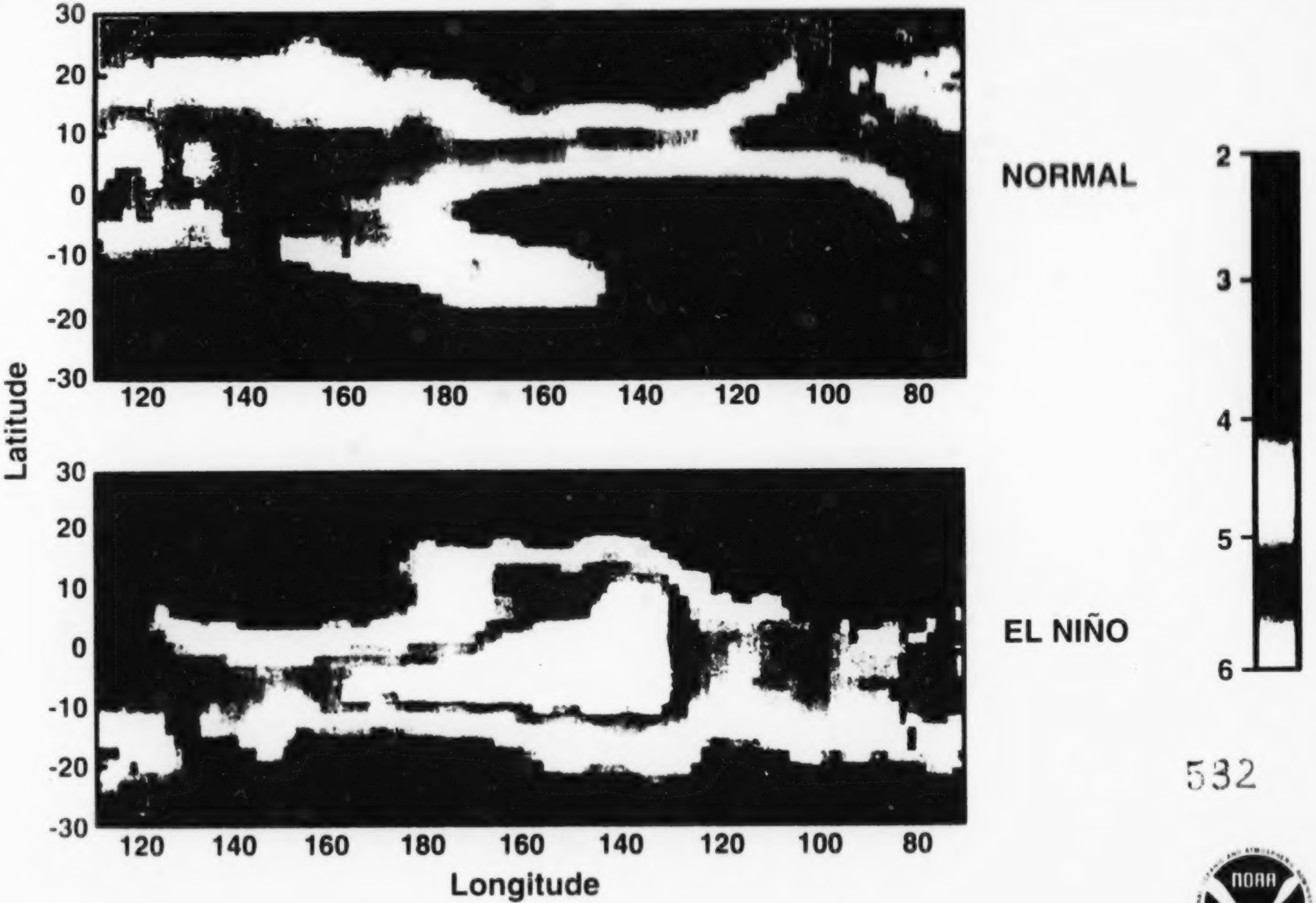
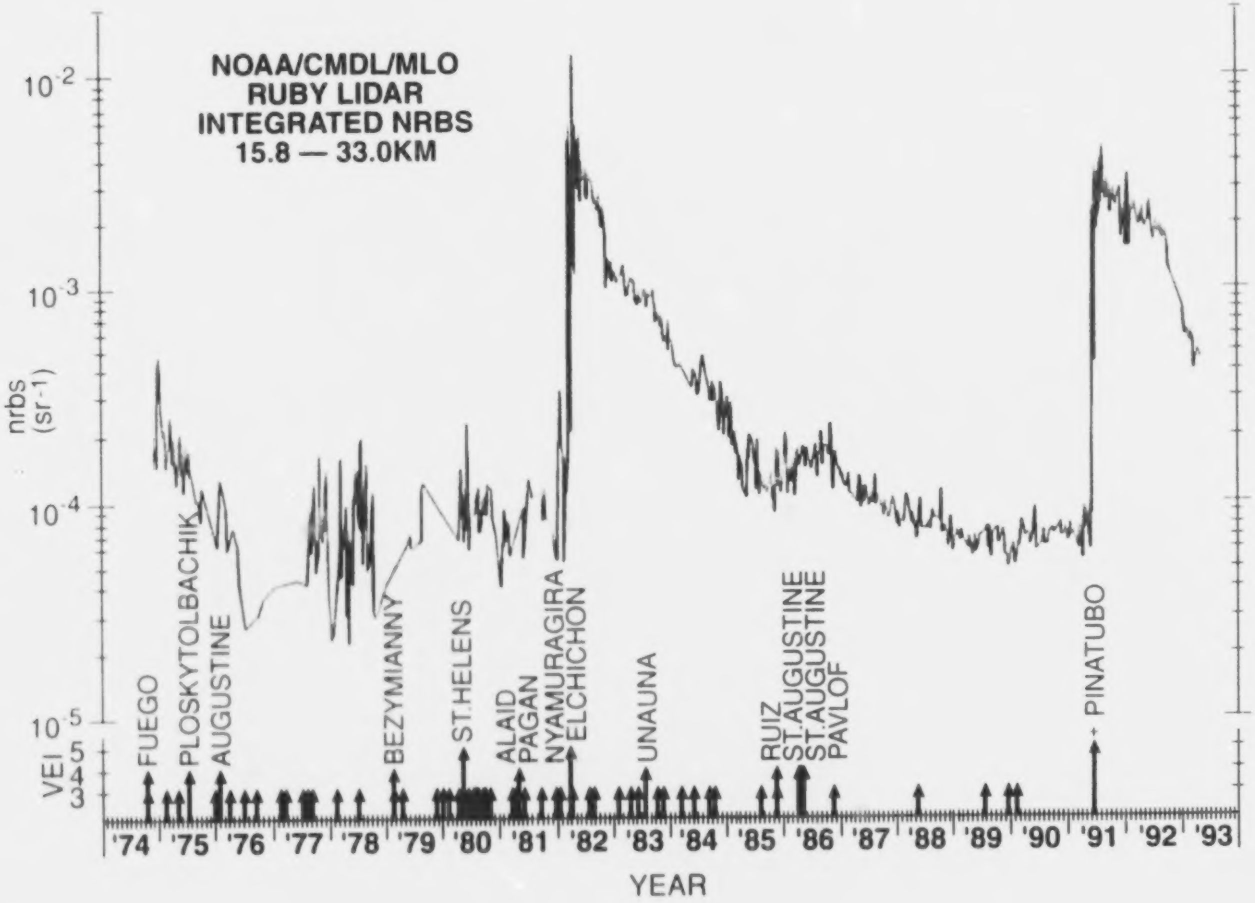
ATMOSPHERIC WATER VAPOR

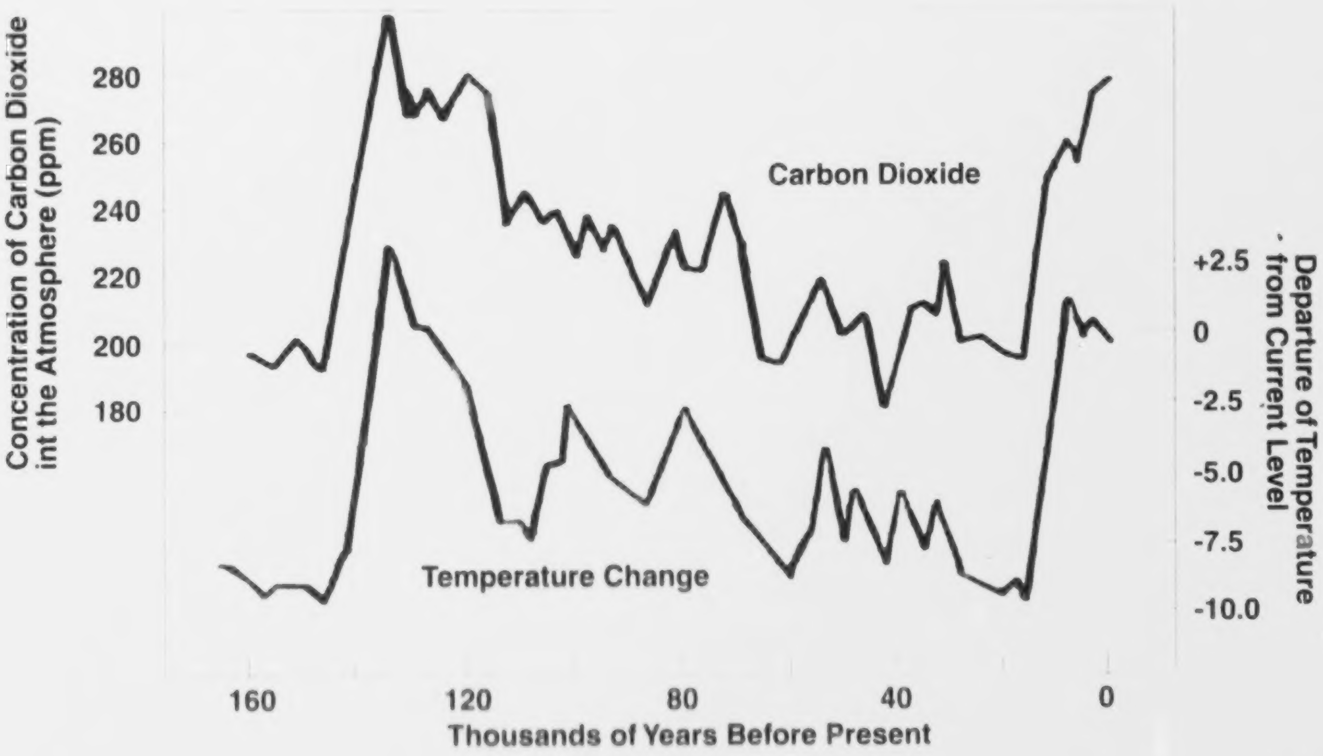

30
20
10
0
-10
-20
-30
120
140
160
180
160
140
120
100
80
NORMAL
Latitude
30
20
10
0
-10
-20
-30
120
140
160
180
160
140
120
100
80
EL NIÑO
Longitude
2
3
4
5
6

BEST COP ABLE

VOLCANIC ATMOSPHERIC PARTICLES

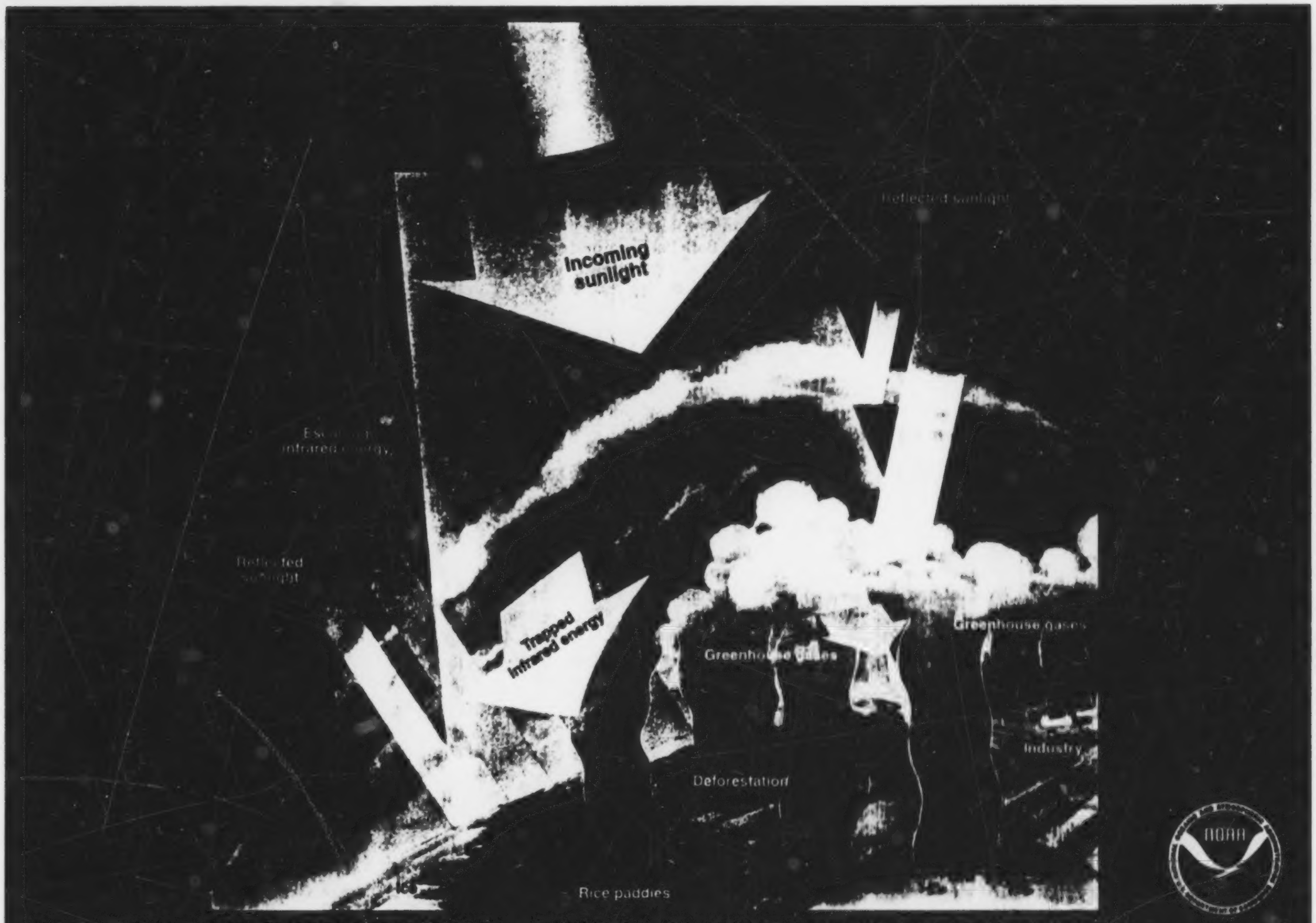


GLOBAL TEMPERATURE AND ATMOSPHERIC CARBON DIOXIDE



Source: J.M. Barnola, *et al.*, "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2," *Nature*, Vol. 329, No. 6138 (1987), p. 410, as cited in World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1990-91*, (Oxford University Press, New York, 1990).

THE GLOBAL GREENHOUSE


Incoming sunlight
Reflected sunlight
Escaping infrared energy
Reflected sunlight
Trapped infrared energy
Greenhouse gases
Greenhouse gases
Industry
Deforestation
Rice paddies
Ice

Artist: Ian Warpole. Source: *Oceanus* magazine, Vol. 35, No. 1, Spring 1992, the Woods Hole Oceanographic Institution, Woods Hole, MA

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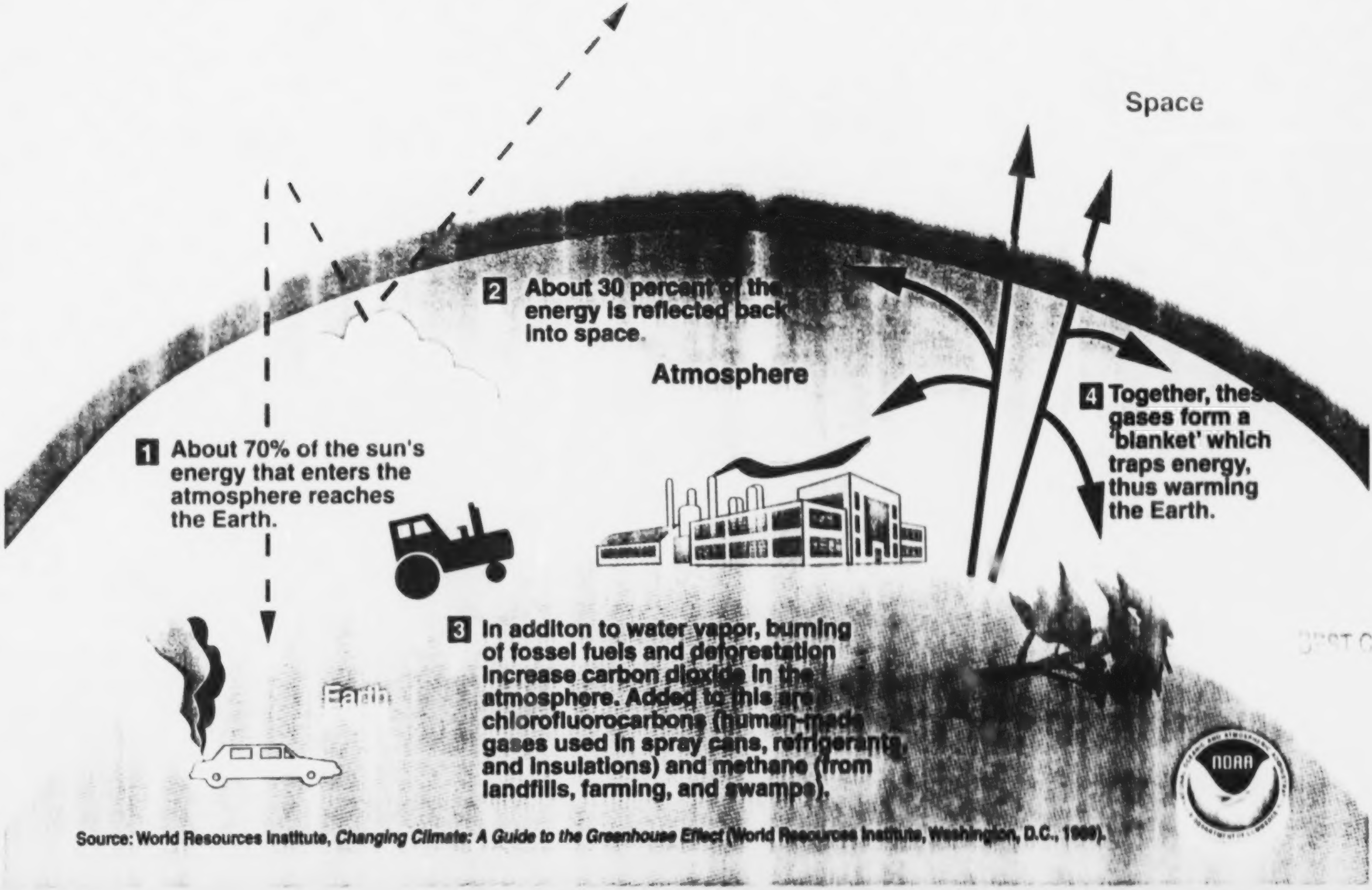
HOW THE GREENHOUSE EFFECT WORKS



1 About 70% of the sun's energy that enters the atmosphere reaches the Earth.

2 About 30 percent of the energy is reflected back into space.

3 In additon to water vapor, burning of fossel fuels and deforestation increase carbon dioxide in the atmosphere. Added to this are chlorofluorocarbons (human-made gases used in spray cans, refrigerants, and insulations) and methane (from landfills, farming, and swamps).

4 Together, these gases form a 'blanket' which traps energy, thus warming the Earth.

Source: World Resources Institute, *Changing Climate: A Guide to the Greenhouse Effect* (World Resources Institute, Washington, D.C., 1989).

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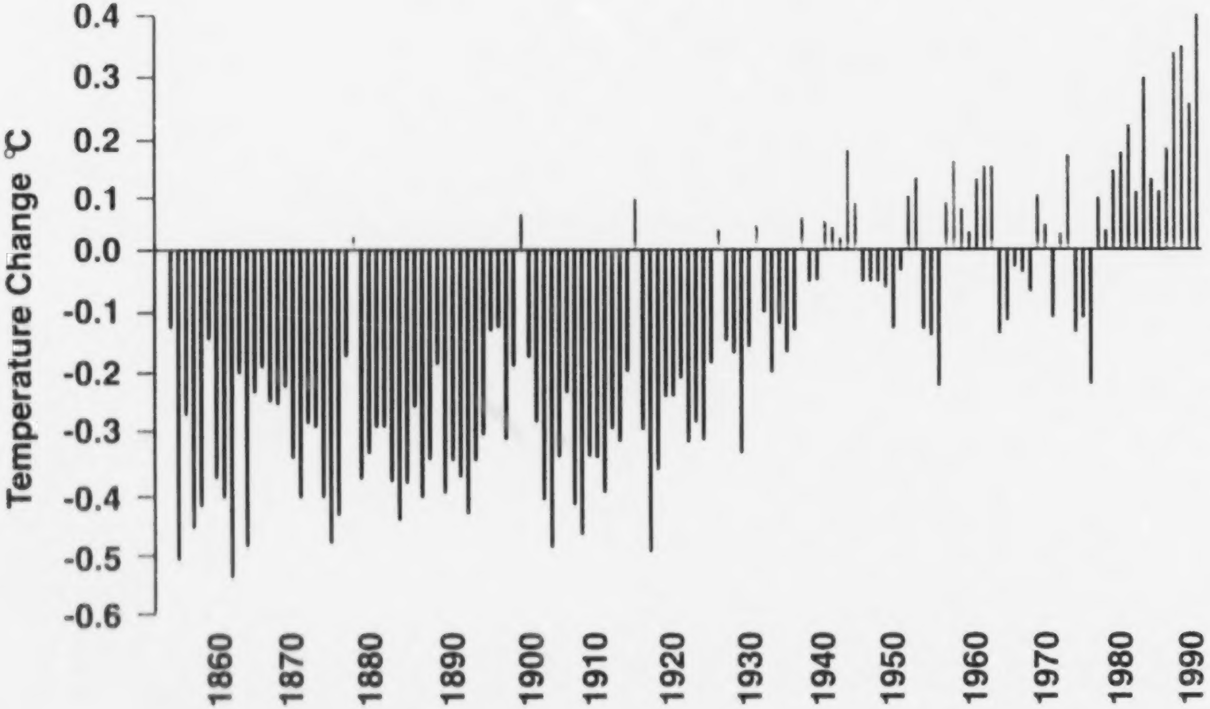
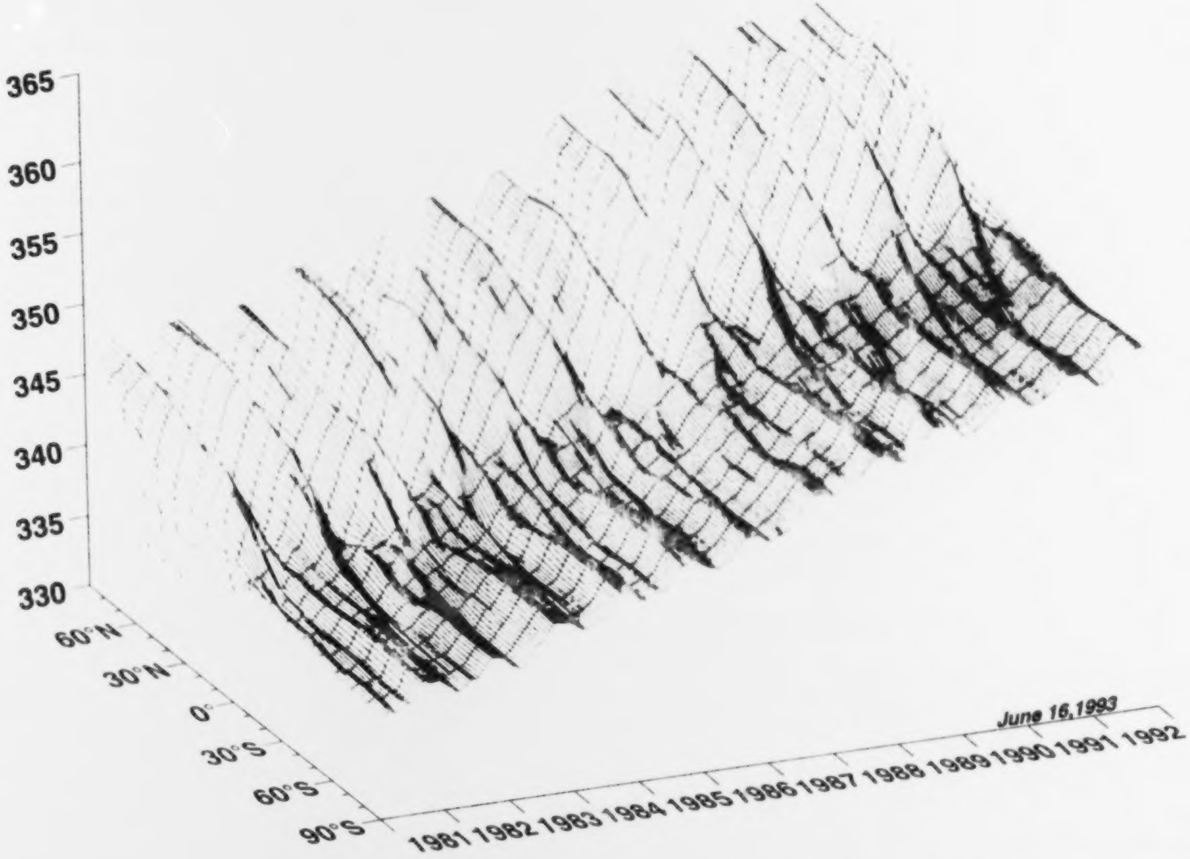
GLOBAL MEAN TEMPERATURE



Note: Deviations from a global temperature of 15°C for the period from 1854-1990.

Source:P.D. Jones and T.M. L. Wigley, CDIAC 1991.

GLOBAL DISTIBUTION OF ATMOSPHERIC CARBON DIOXIDE



Source: Three dimensional representation of the global distribution of atmospheric carbon dioxide in the marine boundary layer assuming no variation with longitude. Data from the NOAA/CMDL Global Cooperative Air Sampling Network were used. The surface represents data smoothed in time and latitude. Principal investigators: Pieter Tans and Thomas Conway, NOAA/CMDL Carbon Cycle Group, Boulder, Colorado; (303) 497-6678

"GREENHOUSE EFFECT"

INCREASING TRACE GASES

?

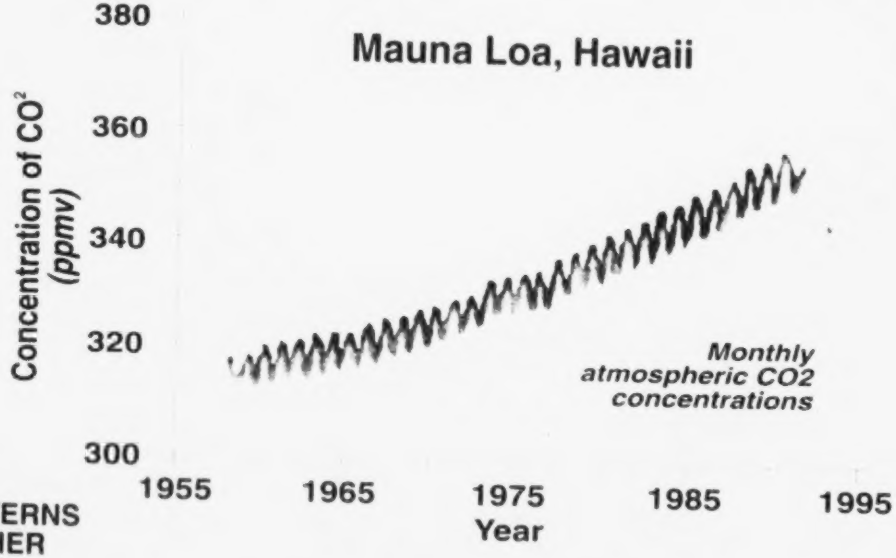
GLOBAL WARMING

?

CHANGES IN: RAINFALL PATTERNS
SEVERE WEATHER
SEA LEVEL

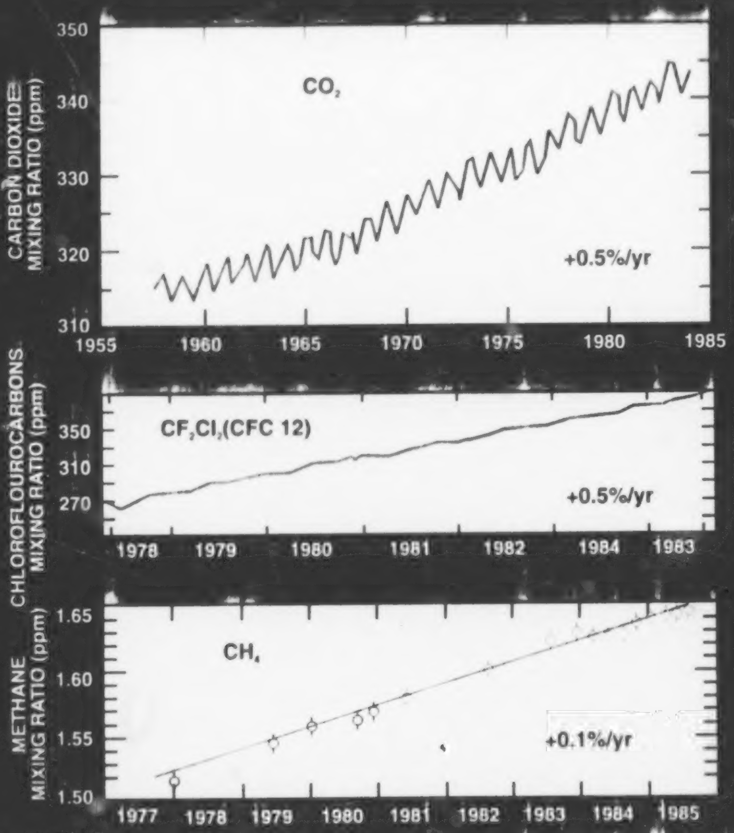
?

IMPACTS: AGRICULTURAL PRODUCTIVITY
NATURAL ECOSYSTEMS STRESS
COASTAL FLOODING
INCREASED DESERTIFICATION
HUMAN HEALTH HAZARDS



CHANGES IN GLOBAL ATMOSPHERIC COMPOSITION

THE FACTS—INCREASING TRACE GAS CONCENTRATION



SOURCES

FOSSIL FUEL CONSUMPTION
FOREST BURNING

REFRIGERANTS
FOAM BLOWING
SOLVENTS

RICE PADDIES?
MARSHLANDS?
ENTERIC FERMENTATION?

➡ CAN LEAD TO SIGNIFICANT GLOBAL WARMING VIA "GREENHOUSE" EFFECT

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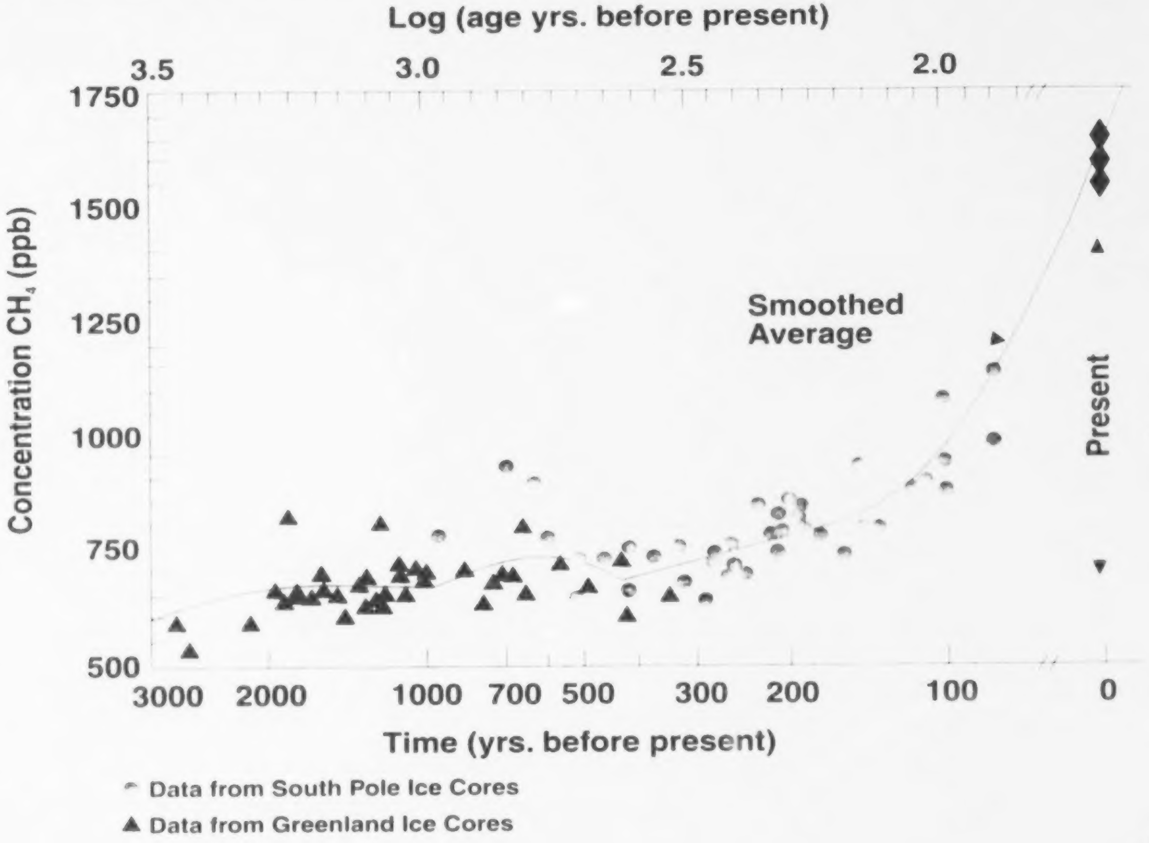
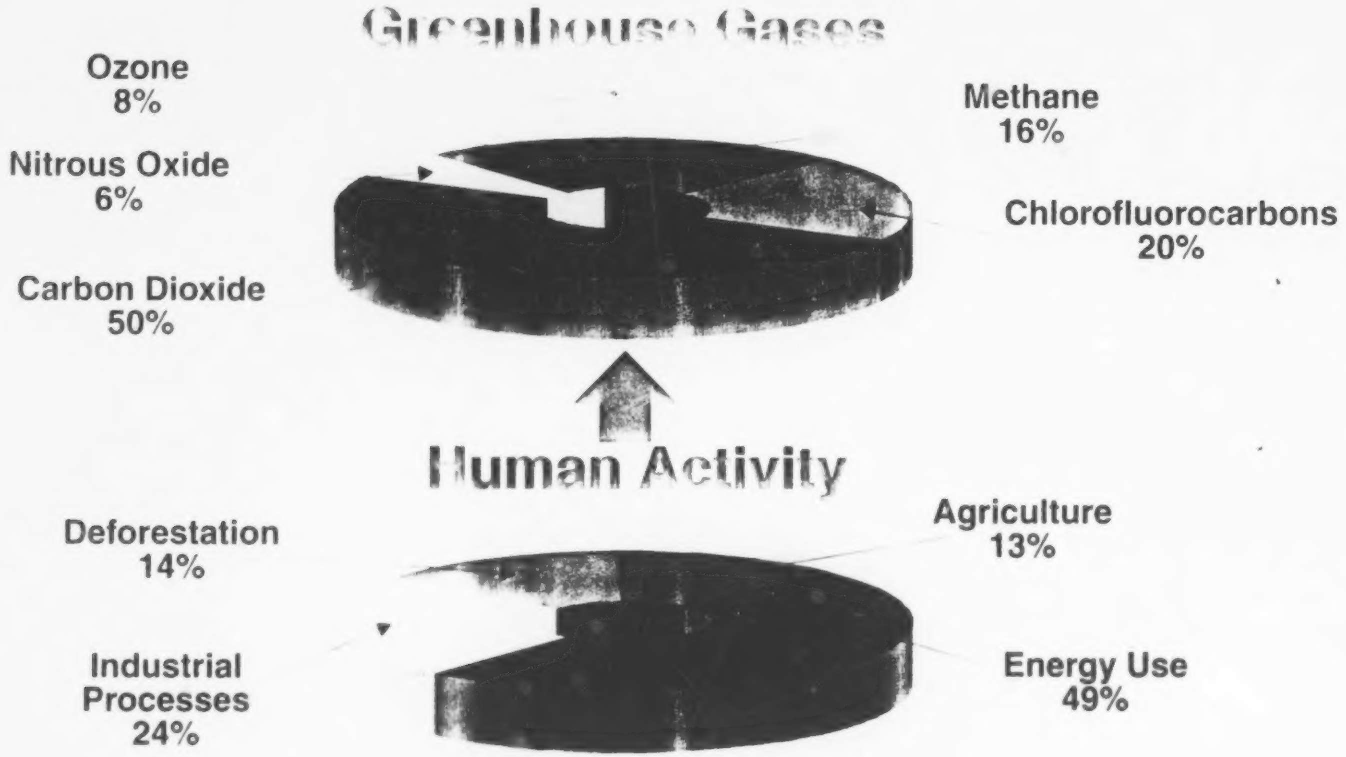
ATMOSPHERIC METHANE CONCENTRATIONS



Source: Rasmussen, R. A., and M. A. K. Khalil, Atmospheric methane in the recent and ancient atmospheres: Concentrations, trends and interhemispheric gradient, *Journal of Geophysical Research*, 89:11599-11605 (1984).

SOURCES & COMPOSITION OF GREENHOUSE GASES



Source: World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, World Resources 1990-91 (Oxford University Press, New York, 1990), Table 2.4, p. 24.

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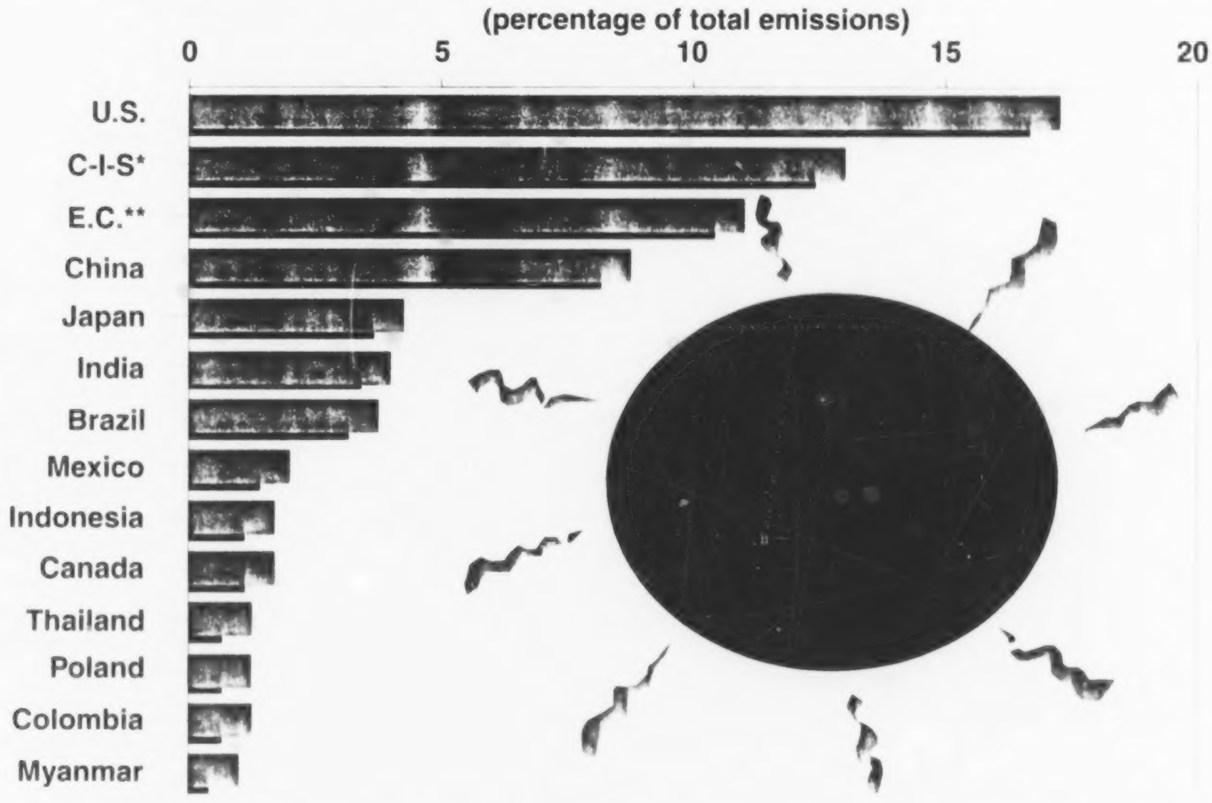
GREENHOUSE INDEX: COUNTRIES WITH HIGHEST GREENHOUSE GAS EMISSIONS, 1989



* Note: The Confederation of Independent States (C-I-S) from the former Soviet Union.

**Note: The European Community (EC) comprises 12 countries: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom.

Sources: (1) Intergovernmental Panel on Climate Change (IPCC), *Climate Change: The IPCC Scientific Assessment*, J. Houghton, G.J. Jenkins, and J.J. Ephraums, eds. (Cambridge University Press, Cambridge, U.K., 1990). (2) World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1992–93* (Oxford University Press, New York, 1992), Tables 24.1 and 24.2.

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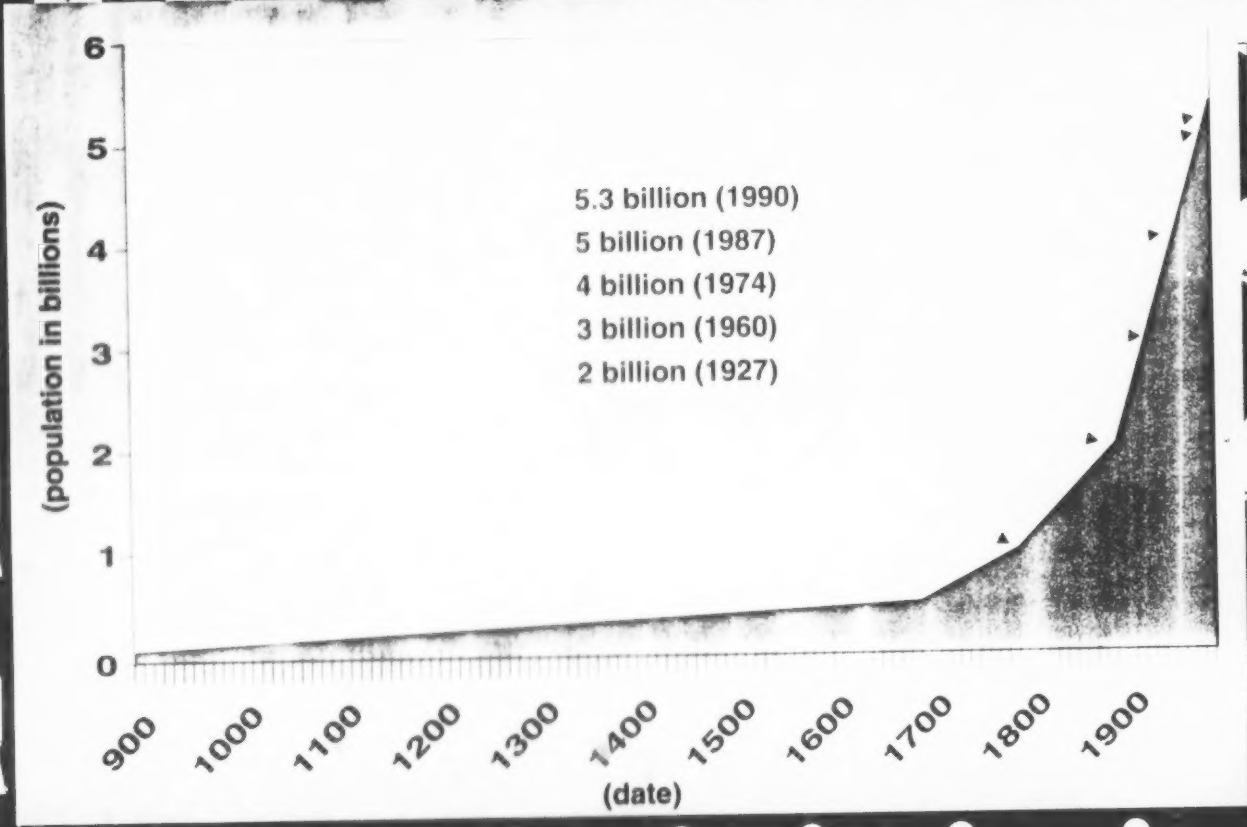
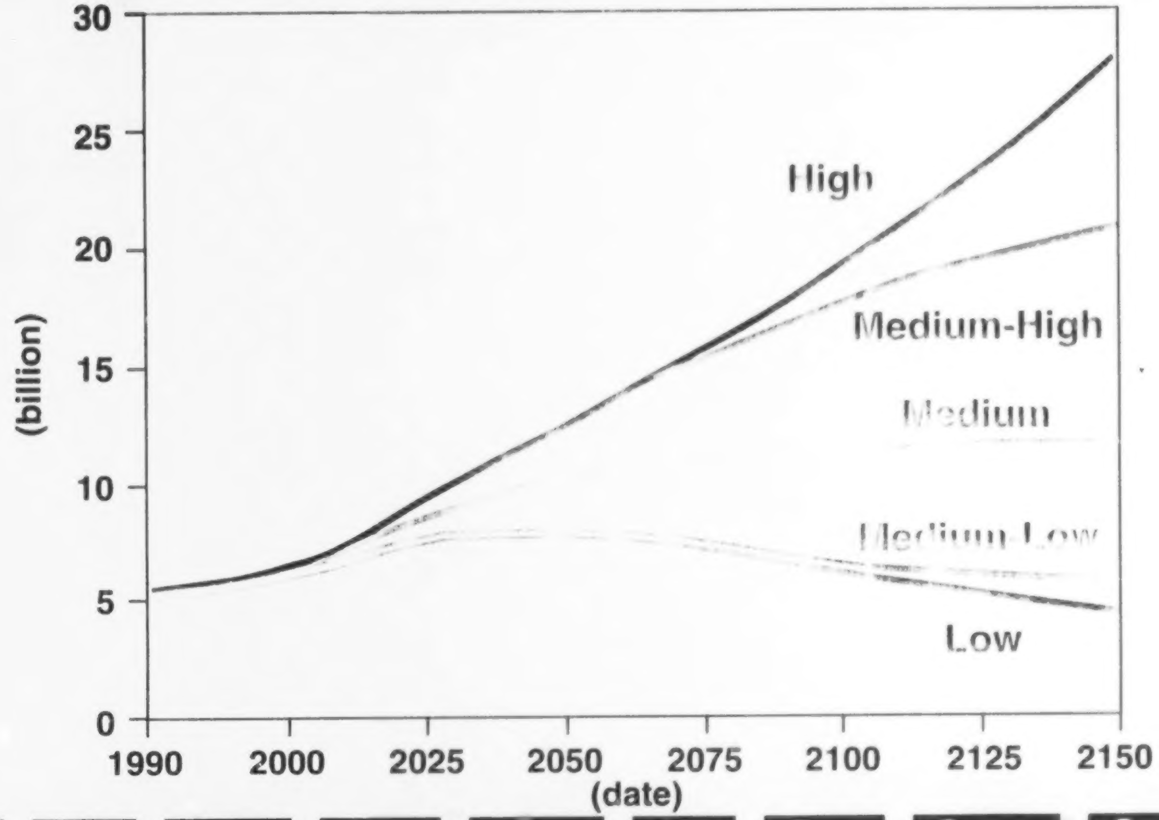
WORLD POPULATION GROWTH, 900 AD – 1990 AD



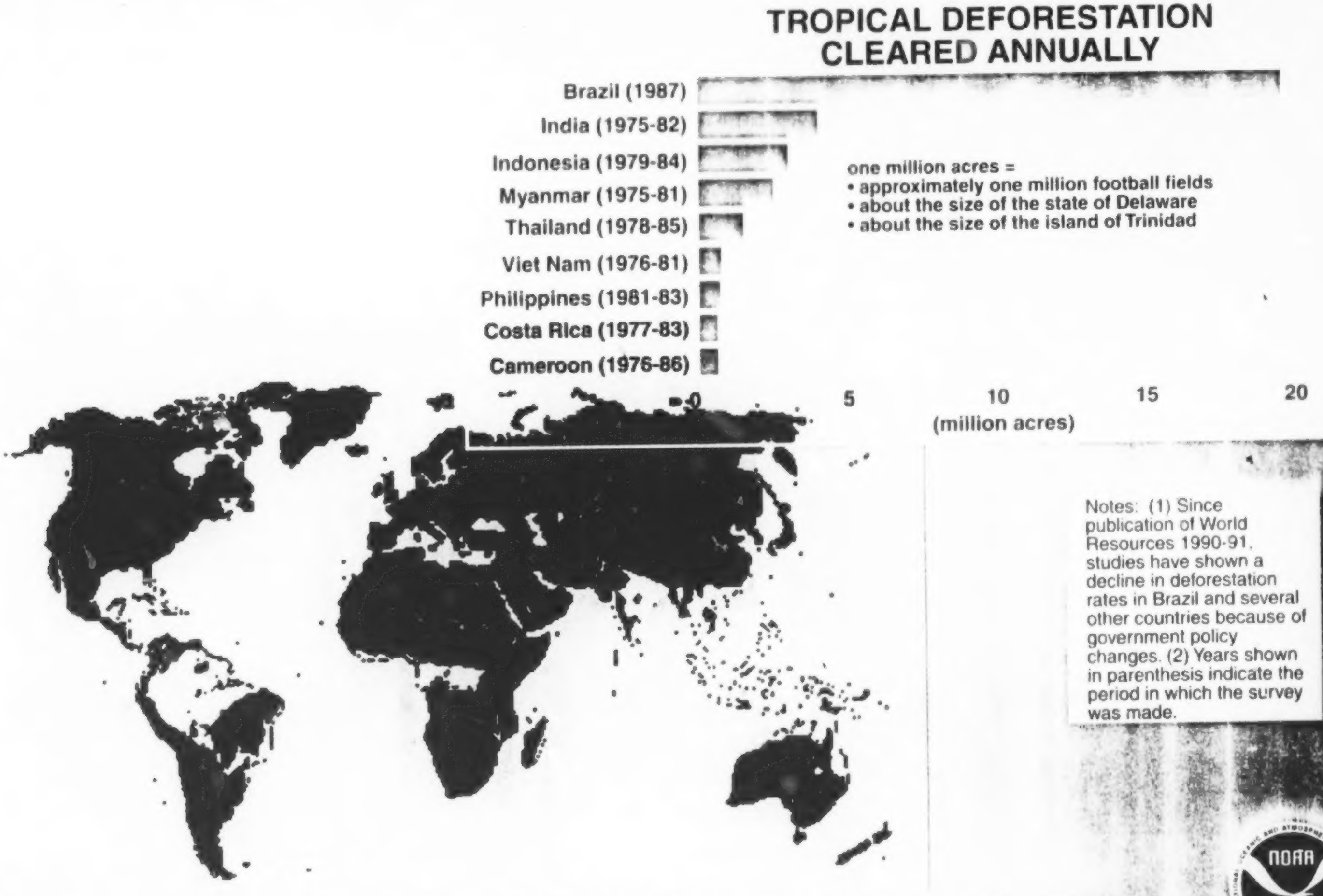
Source Population Reference Bureau (1989)

PROJECTED POPULATION OF THE WORLD, 1990 – 2150



Source: United Nations Population Division, *Long-Range World Population Projections: Two Centuries of Population Growth, 1950–2150* (United Nations. New York, forthcoming), executive

DISTRIBUTION OF TROPICAL FORESTS



one million acres =
- approximately one million football fields
- about the size of the state of Delaware
- about the size of the island of Trinidad

Notes: (1) Since publication of World Resources 1990-91, studies have shown a decline in deforestation rates in Brazil and several other countries because of government policy changes. (2) Years shown in parenthesis indicate the period in which the survey was made.

Source: World Resources Institute in collaboration with the United Nations Environment Programme and the United Nations Development Programme, *World Resources 1990-91* (Oxford University Press, New York, 1990).

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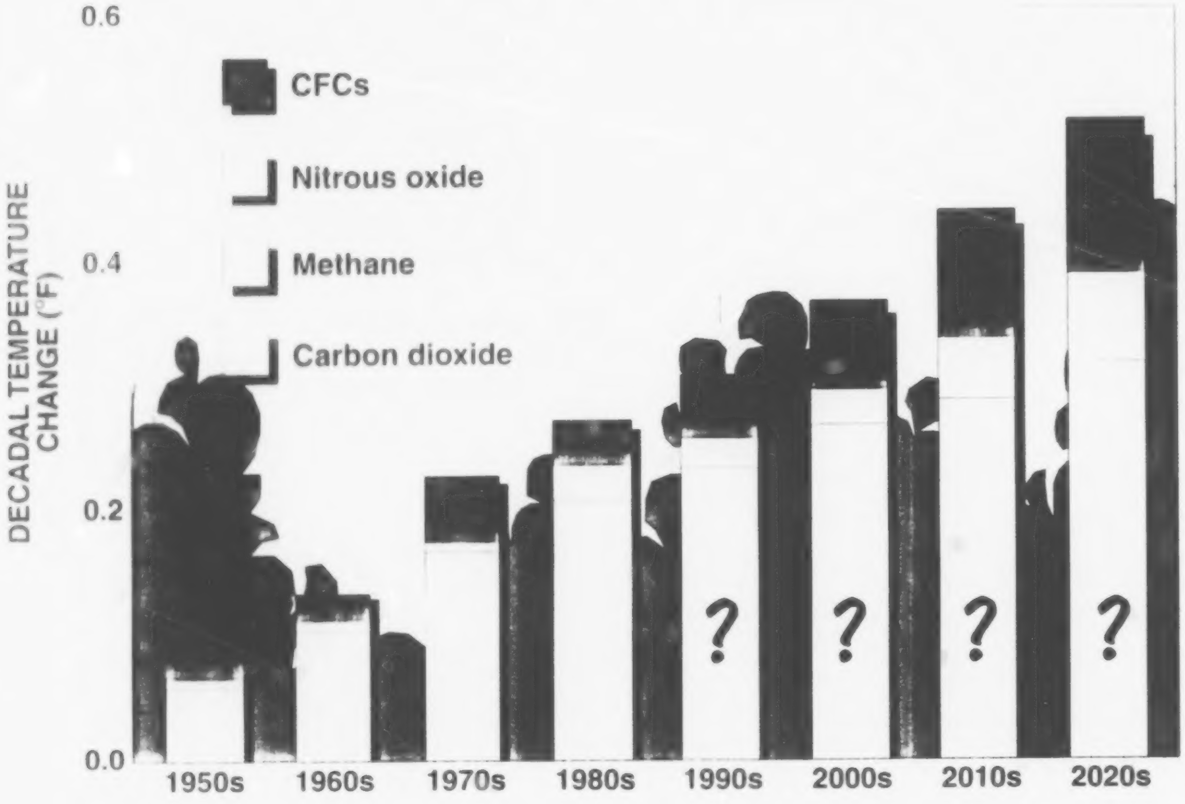
FUTURE GREENHOUSE GAS TRENDS UNDER DOUBLE CO_2 CONDITIONS



Source: NASA Goddard Institute for Space Studies (GISS) computer model simulation, "NASA Facts," Goddard Space Flight Center, Greenbelt, Maryland 20771

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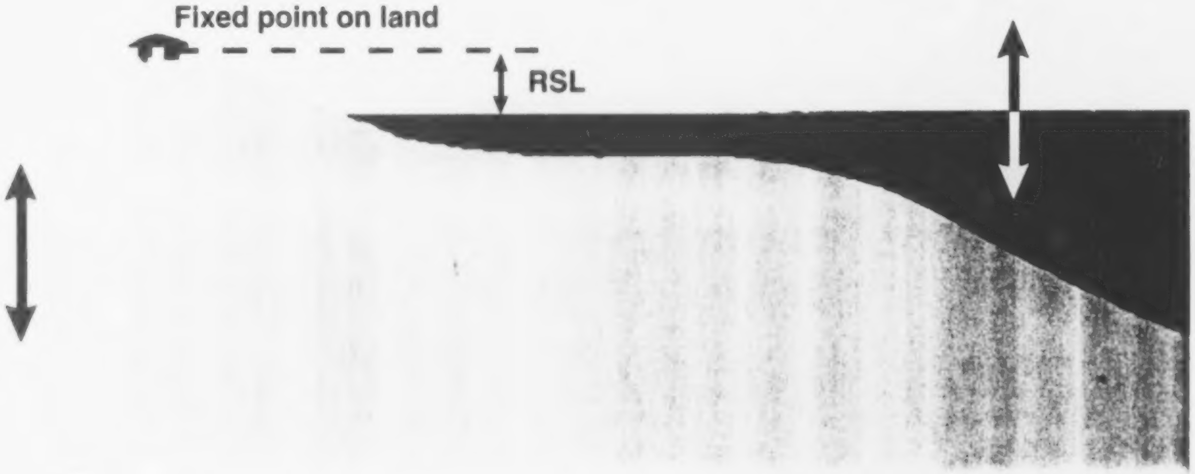
CAUSES OF RELATIVE SEA LEVEL (RSL) CHANGE



Vertical Land Movement:

- isostatic adjustments
- tectonic effects
- sedimentation
- human factors (groundwater and oil extraction)

Changes in Level of Ocean Surface:

- melting glaciers, ice sheets
- ocean currents, tides
- hydrologic cycle changes
- expansion or contraction (steric effects)

Source: EarthQuest Science Capsule, "Sea Level Rise," OIES, Spring, 1993

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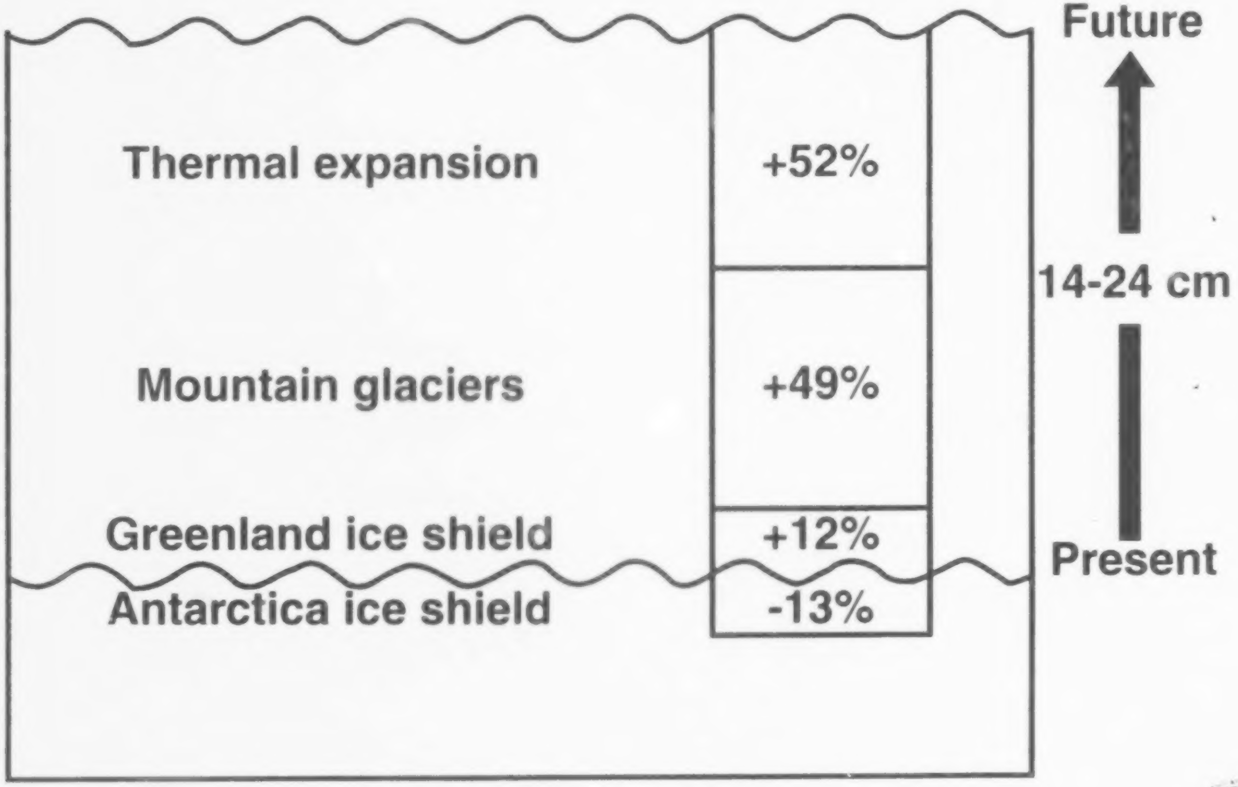
FACTORS PROJECTED TO CONTRIBUTE TO SEA LEVEL RISE FROM 1985 TO 2030



Future

Thermal expansion +52%

Mountain glaciers +49%

Greenland ice shield +12%

Antarctica ice shield -13%

14-24 cm

Present

Source: Warrick et al., 1990

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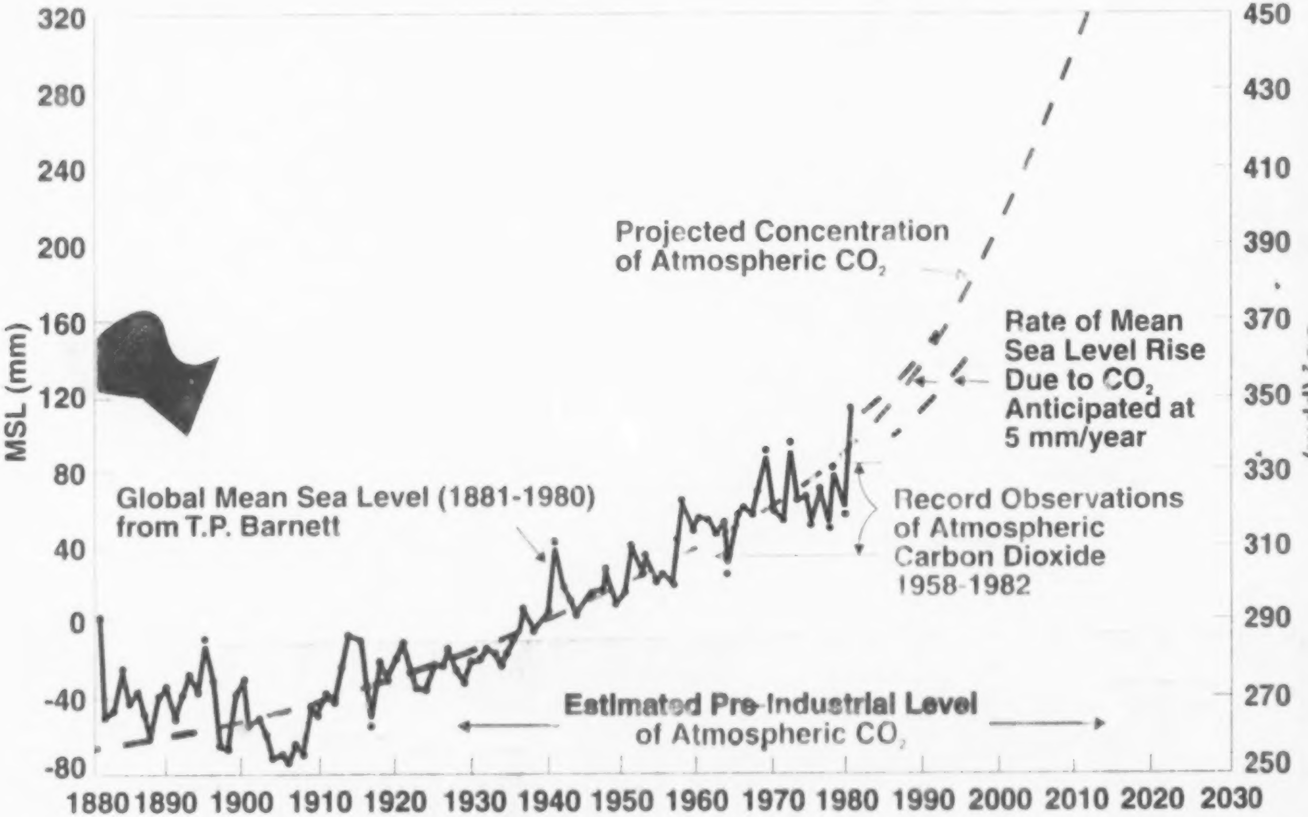
ATMOSPHERIC CO2 AND SEA LEVEL RISE



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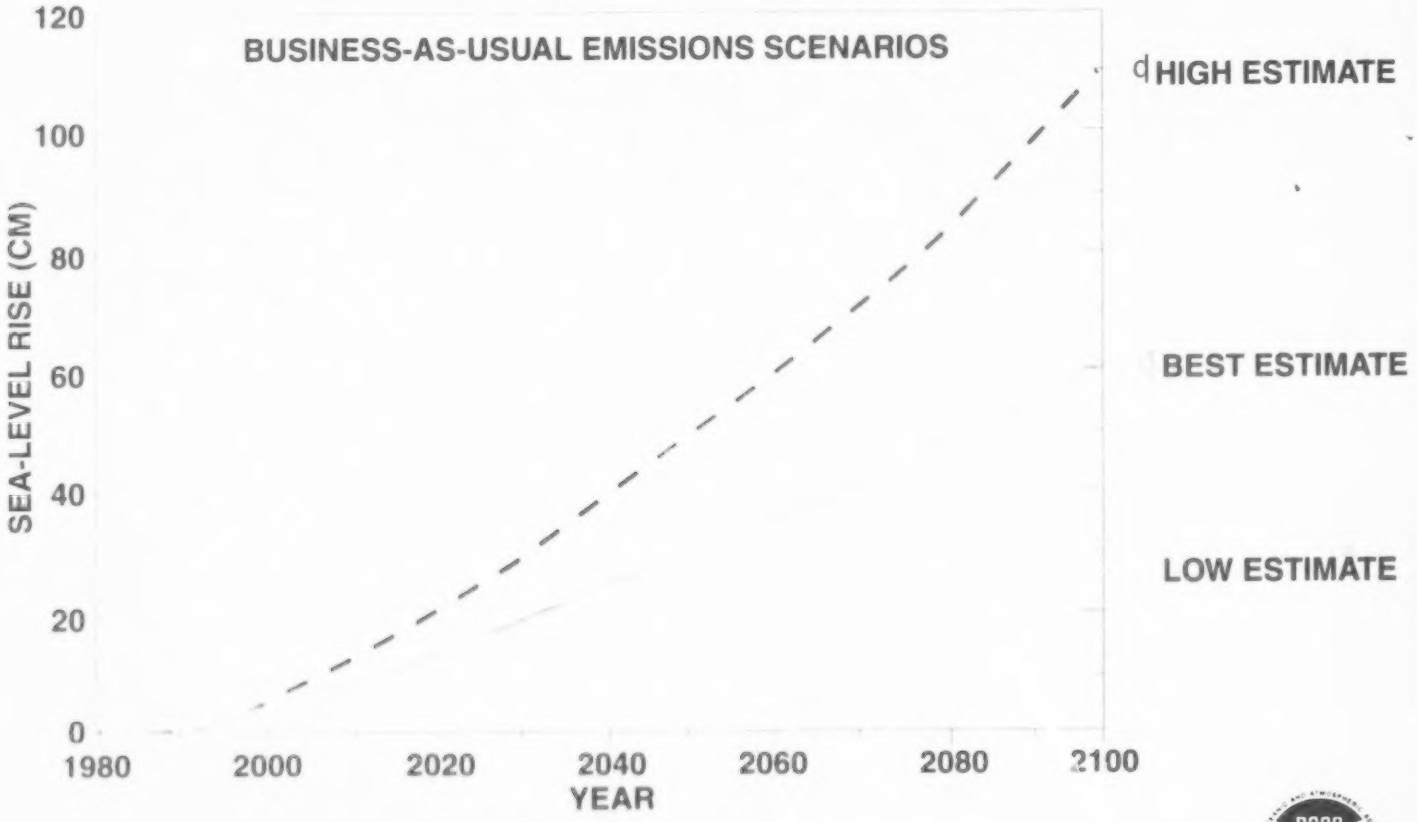
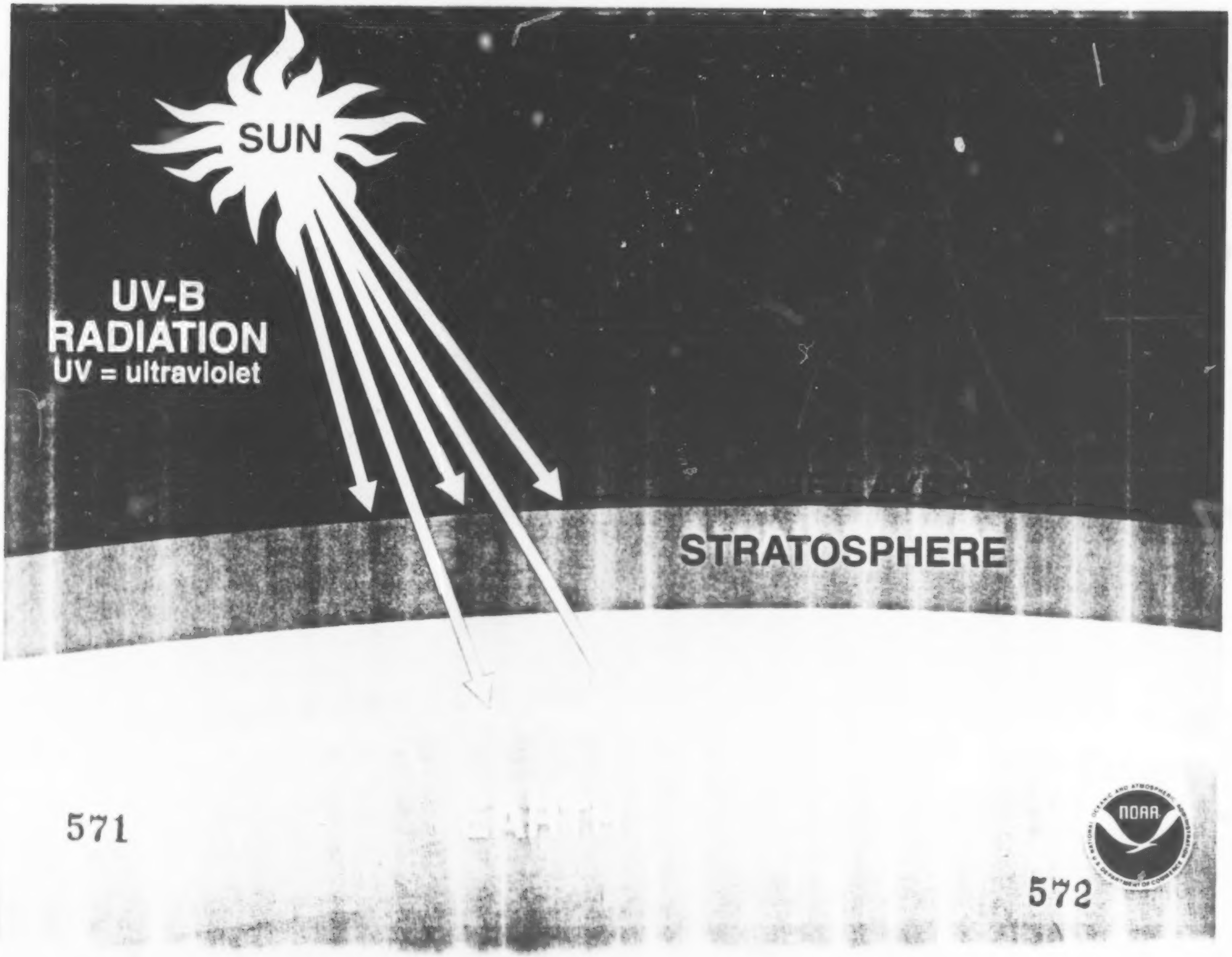
SEA-LEVEL RISE SCENARIOS



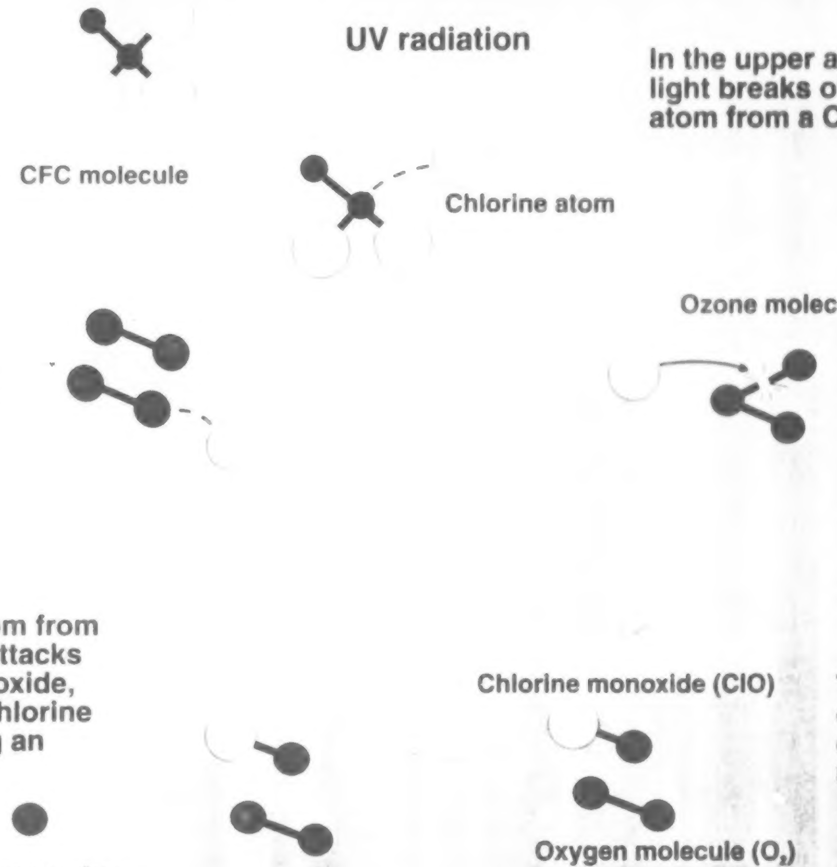
Source: U.N. Intergovernmental Panel on Climate Change, Scientific Assessment, 1990

THE OZONE LAYER


SUN
UV-B
RADIATION
UV = ultraviolet
STRATOSPHERE
EARTH

BEST COPY AVAILABLE

HOW OZONE IS DESTROYED


UV radiation
CFC molecule
Chlorine atom
Ozone molecule (O_3)
Chlorine monoxide (ClO)
Oxygen molecule (O_2)
Free oxygen atom

In the upper atmosphere UV light breaks off a chlorine atom from a CFC molecule.

2

The chlorine atom attacks an ozone molecule, breaking it apart and so destroying the ozone.

3

This forms an ordinary oxygen molecule and chlorine monoxide molecule.

A free oxygen atom from the atmosphere attacks the chlorine monoxide, releasing a free chlorine atom and forming an ordinary oxygen

The chlorine is free to repeat the process of destroying more ozone molecules for the next hundred years.

Source: "The Hole Story," University of Hawaii Sea Grant, 1992.

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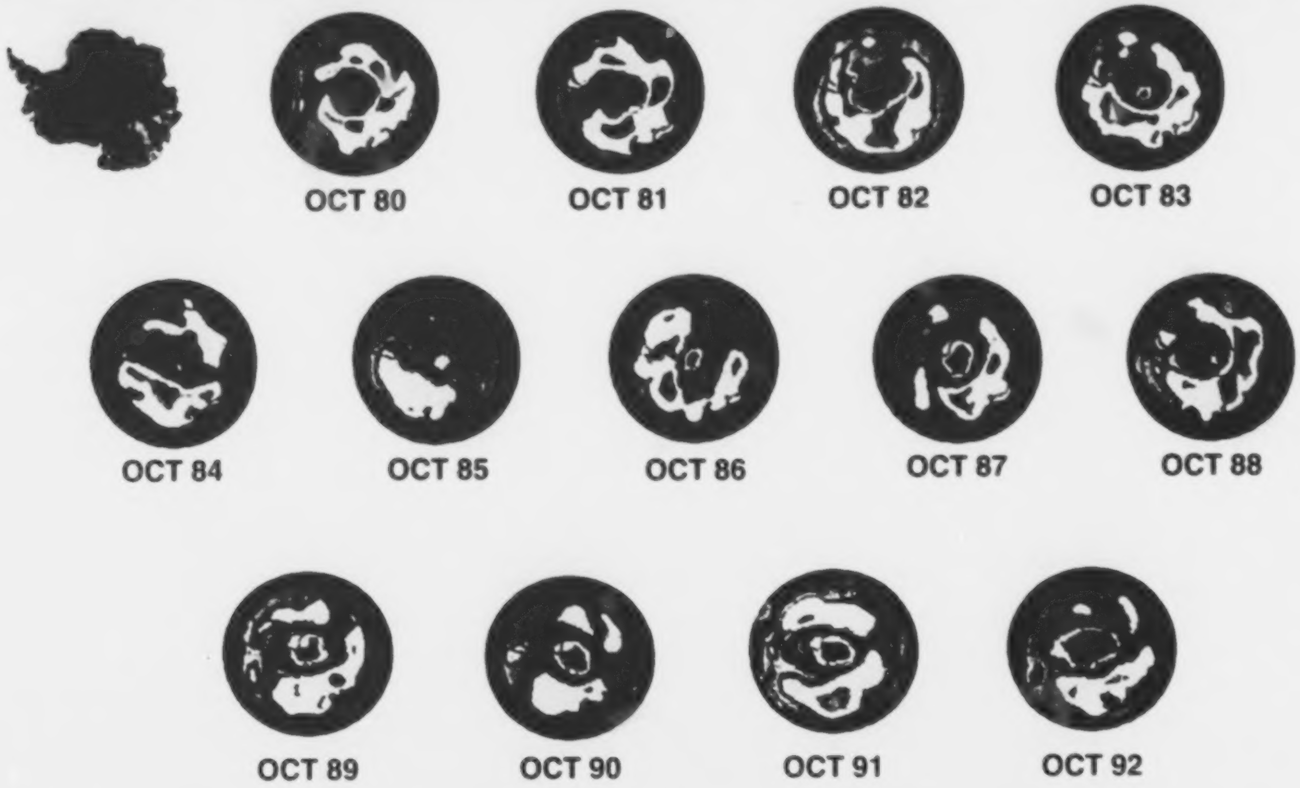
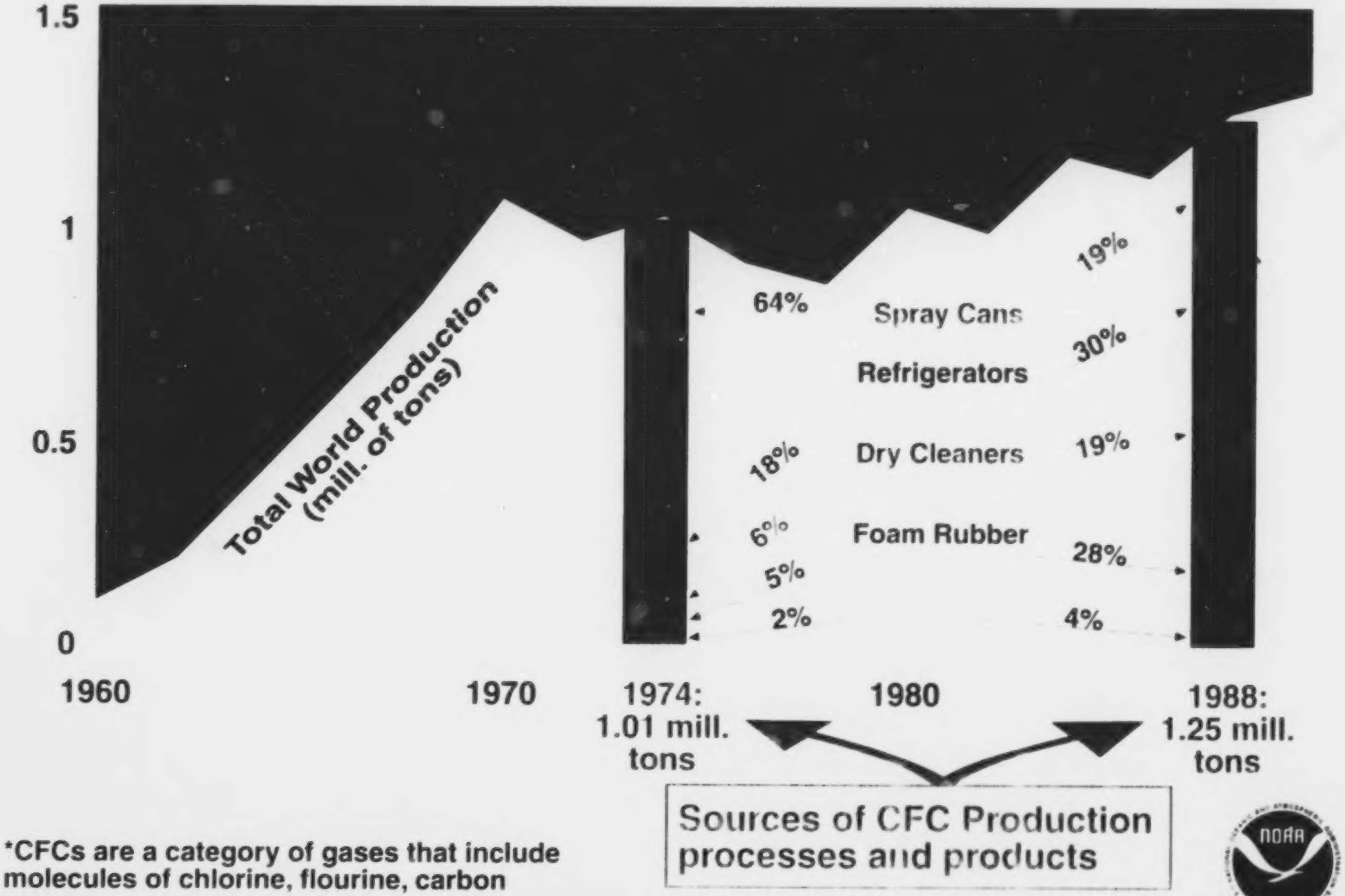
OZONE DEPLETION


OCT 80
OCT 81
OCT 82
OCT 83
OCT 84
OCT 85
OCT 86
OCT 87
OCT 88
OCT 89
OCT 90
OCT 91
OCT 92

The Antartic Ozone Hole is a pollution stimulated annual phenomenon that attains its maximum intensity in mid-October. Data from NOAA's Polar Orbiting TOVS (Tiros Operational Vertical Sounder) is used to display the rapid decline in protective stratospheric ozone over Antarctica during the past dozen years. The growing black spot represents the lowest total

PRODUCTION AND USES OF CFC GASES*



*CFCs are a category of gases that include molecules of chlorine, flourine, carbon

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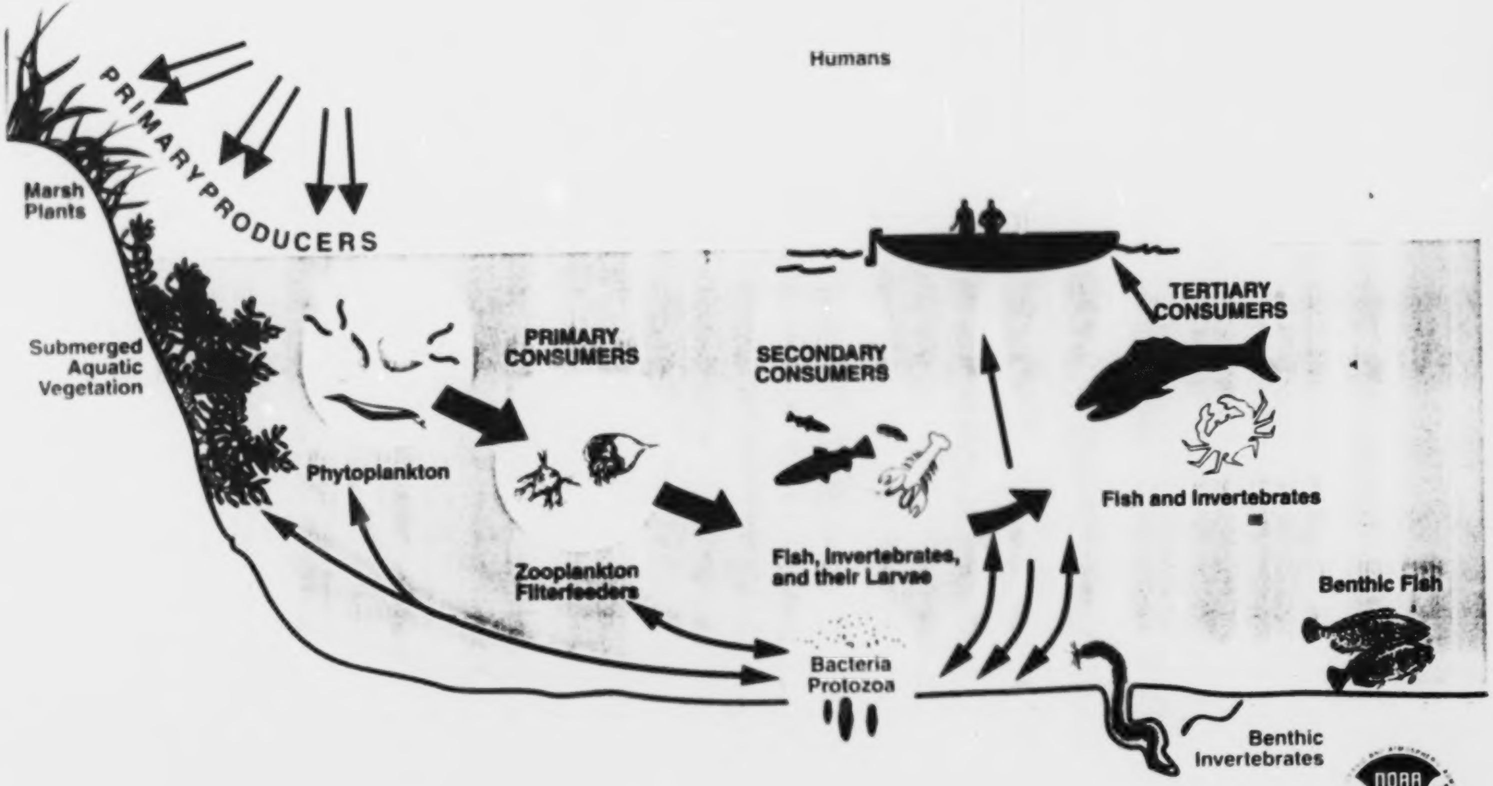
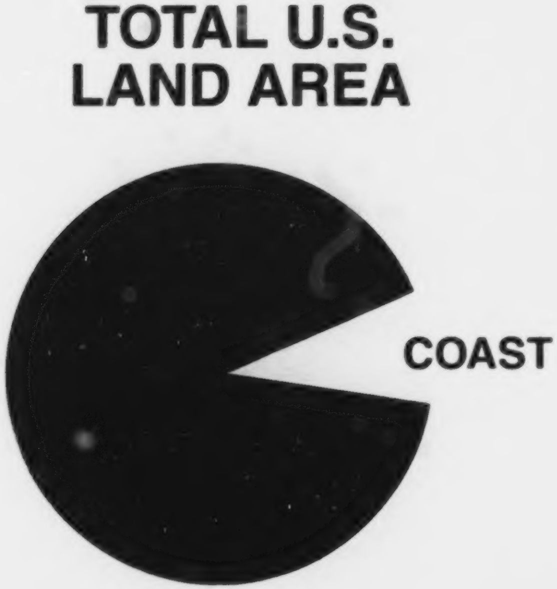
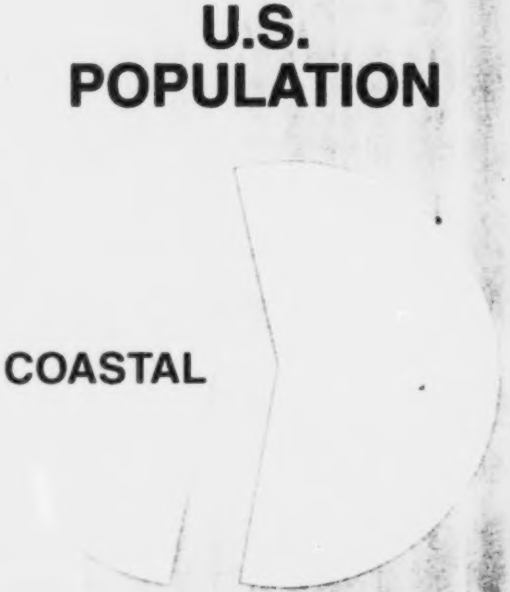
MARINE ECOSYSTEM FOOD WEB


Humans
PRIMARY PRODUCERS
Marsh Plants
Submerged Aquatic Vegetation
Phytoplankton
PRIMARY CONSUMERS
Zooplankton Filterfeeders
SECONDARY CONSUMERS
Fish, Invertebrates, and their Larvae
TERTIARY CONSUMERS
Fish and Invertebrates
Benthic Fish
Bacteria Protozoa
Benthic Invertebrates

Source: UNEP Environment Effects Panel Report, Nov. 1989, p. 40.

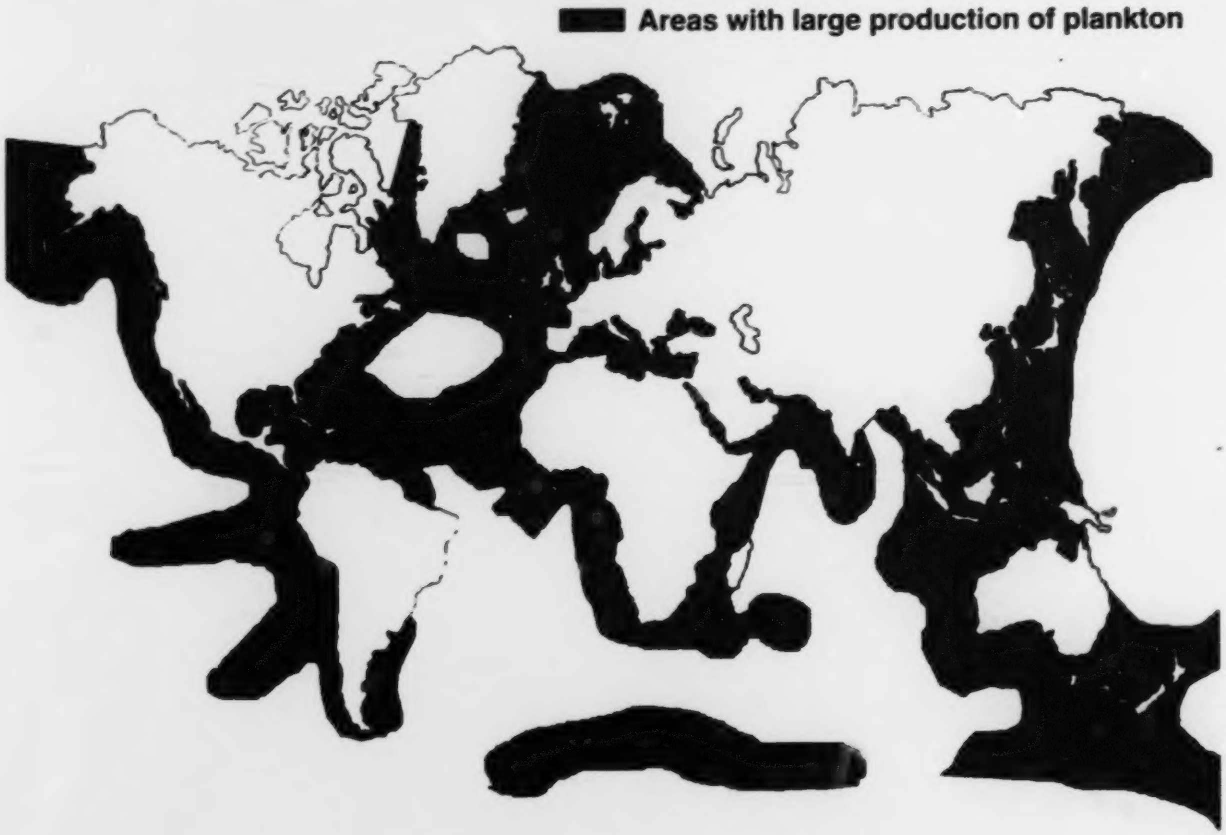
COASTAL POPULATION BY 2010 IN CONTINENTAL U.S.





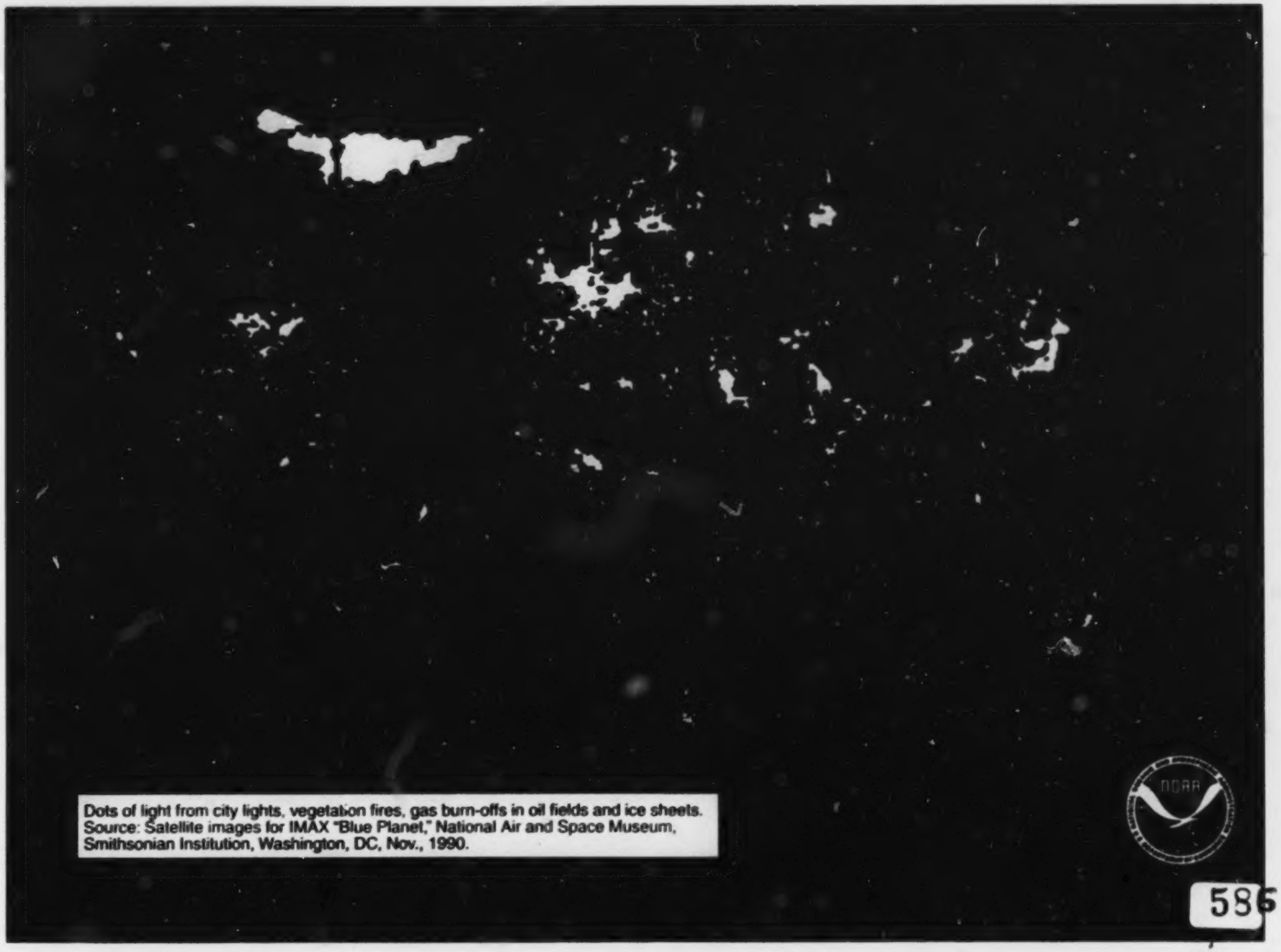
2010 394 PERSONS PER SQUARE MILE
2010 95 PERSONS PER SQUARE MILE

PLANKTON PRODUCTION


■ Areas with large production of plankton

Source: *World Resources*, World Resources Institute, 1990.

EARTH AT NIGHT



Dots of light from city lights, vegetation fires, gas burn-offs in oil fields and ice sheets.
Source: Satellite images for IMAX "Blue Planet," National Air and Space Museum, Smithsonian Institution, Washington, DC, Nov., 1990.

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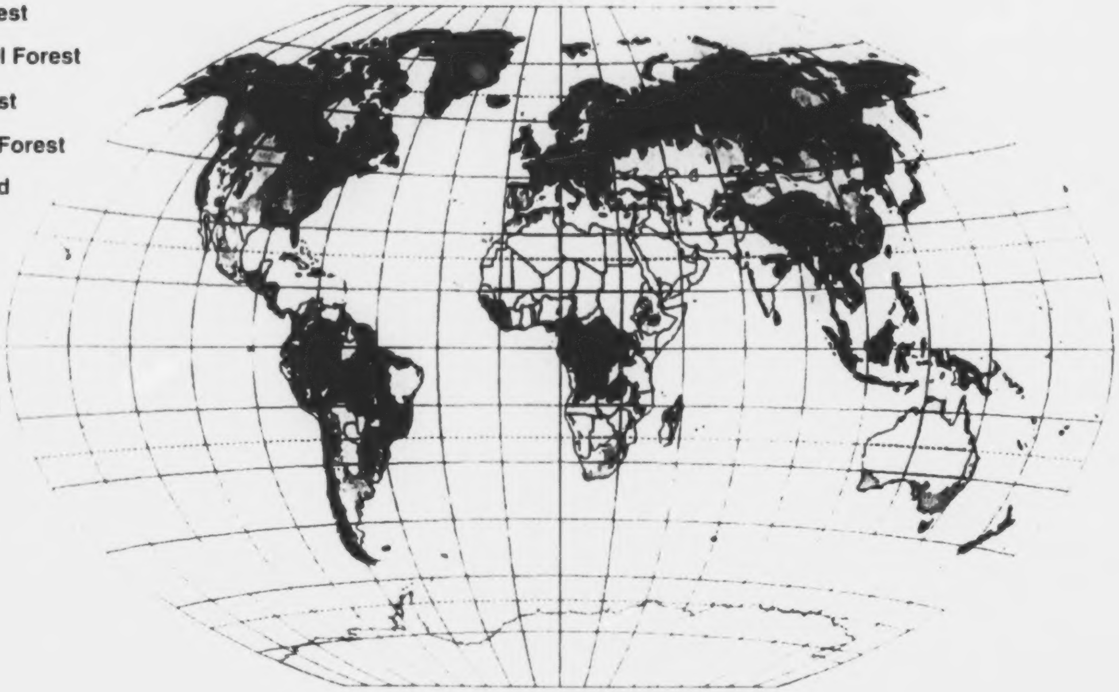
HOLDRIDGE LIFE ZONE CLASSIFICATION

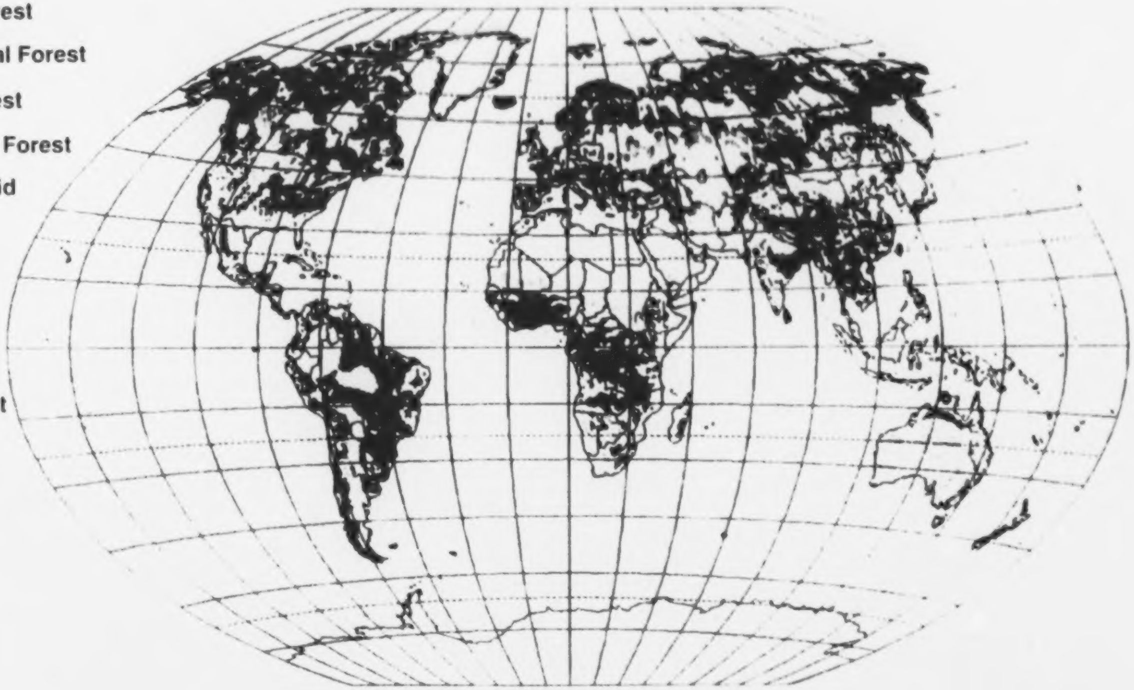
- ■ Tropical Rain Forest
- ■ Tropical Seasonal Forest
- ▨ Tropical Dry Forest
- ■ Warm Temperate Forest
- ☐ Tropical Semi-Arid
- ☐ Hot Desert
- ■ Chapparal
- ☐ Steppe
- ☐ Cool Desert
- ■ Temperate Forest
- ■ Boreal Forest
- ■ Forest Tundra
- ▨ Cold Parklands
- ■ Tundra



Source: Leemans & Prentice, 1990

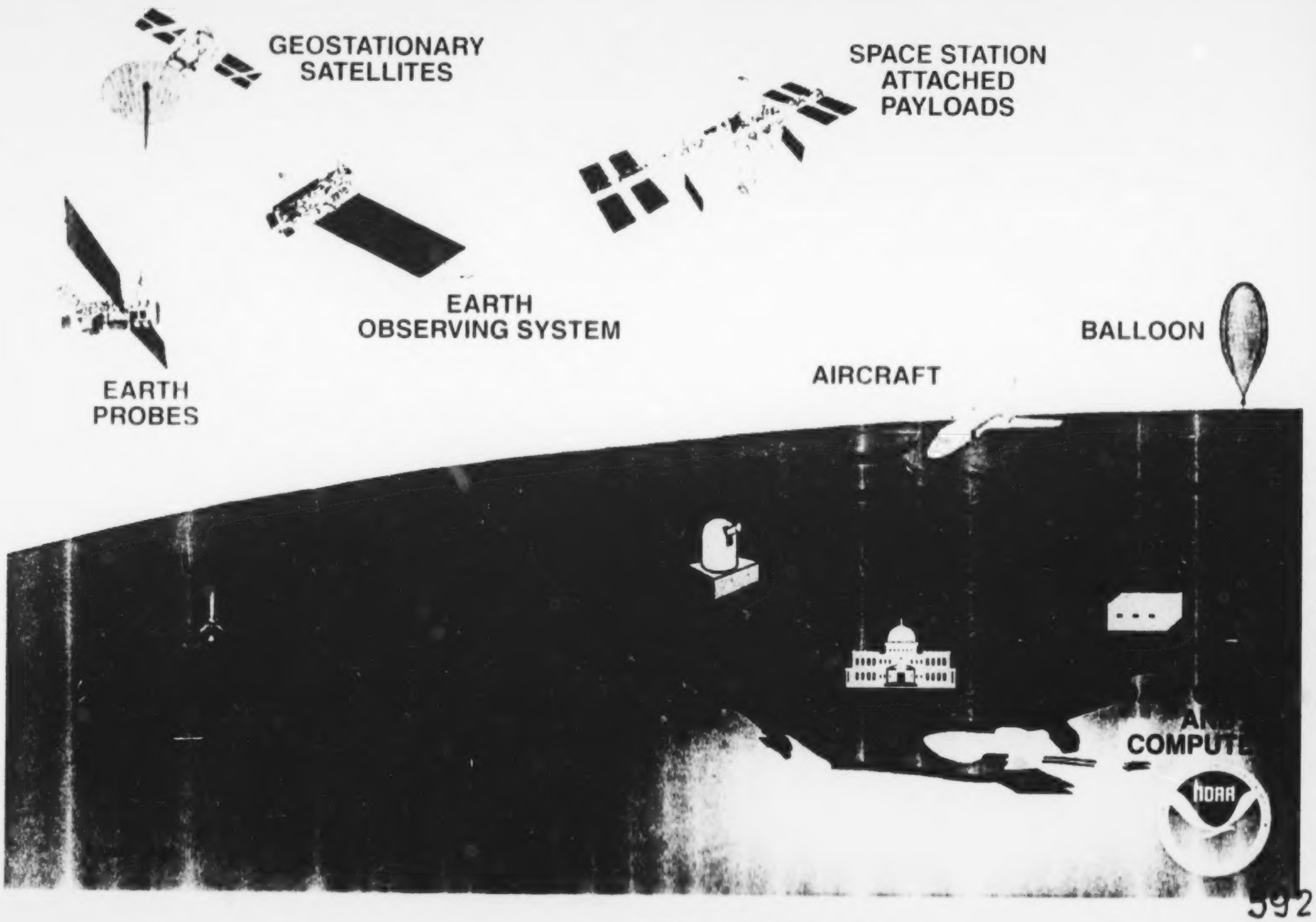
NEW ZONES USING DOUBLE CO_2 COMPUTER MODELING BY OREGON STATE UNIVERSITY

- ■ Tropical Rain Forest
- ■ Tropical Seasonal Forest
- □ Tropical Dry Forest
- ▨ Warm Temperate Forest
- Tropical Semi-Arid
- Hot Desert
- ▨ Chapparal
- □ Steppe
- Cool Desert
- ■ Temperate Forest
- ■ Boreal Forest
- ■ Forest Tundra
- ▨ Cold Parklands
- ■ Tundra



Source: (Leemans, 1990)

A GLOBAL SCALE EXAMINATION OF OUR PLANET


GEOSTATIONARY SATELLITES
SPACE STATION ATTACHED PAYLOADS
EARTH OBSERVING SYSTEM
EARTH PROBES
BALLOON
AIRCRAFT
AN
COMPUTE

BEST COPY AVAILABLE

THE NEW ENVIRONMENTAL ETHIC

Science

Information

Education

Stewardship

Partnership

U.S. Global Change
Research Program

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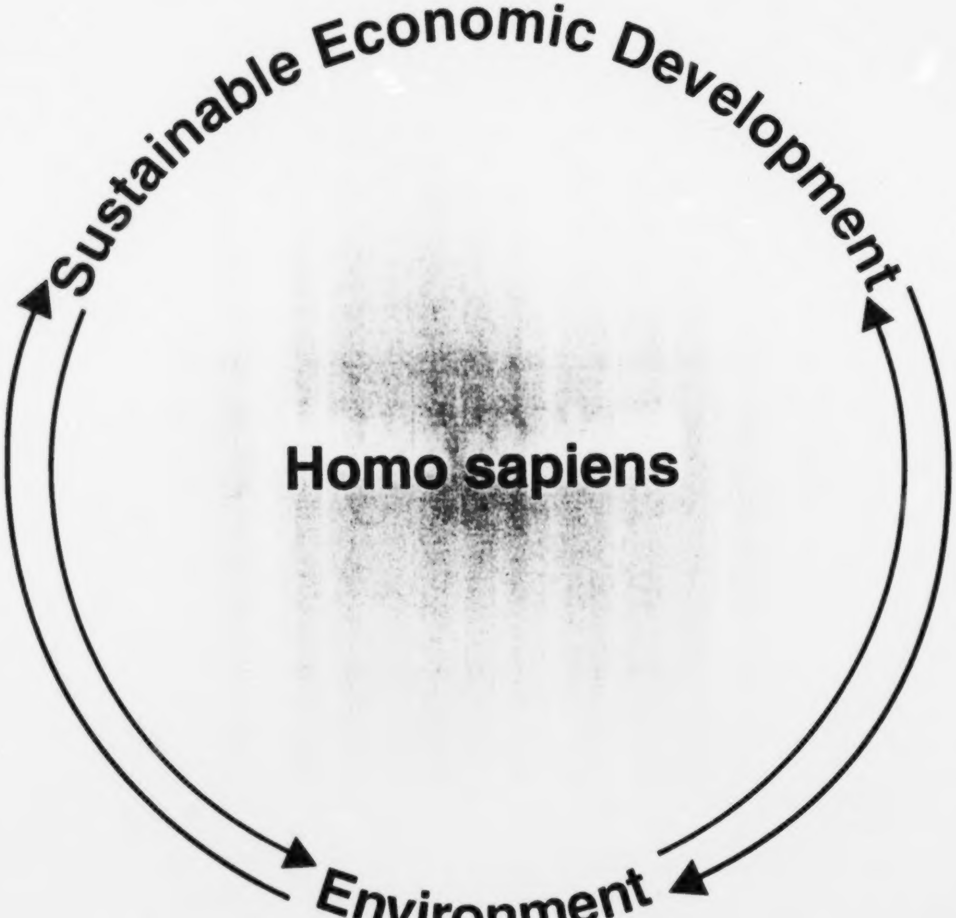
UNCED — "THE RIO DECLARATION"



Sustainable Economic Development

Homo sapiens

Environment

“Predictions” of Climate Change

Expected Effect	Confidence
Large Stratospheric Cooling	Virtually Certain
Global Mean Surface Warming	Very Probable
Global Precipitation Increase	Very Probable
Reduction of Sea Ice	Very Probable
Arctic Winter Surface Warming	Very Probable
Summer Continental Dryness	Probable
Arctic Precipitation Increase	Probable
Rise in Global Mean Sea Level	Probable
Regional Vegetation Changes	Uncertain
Regional Climatic Details	Uncertain
Tropical Storm Increases	Uncertain
Details of Next 25 Years	Uncertain

Source: J. D. Mahlman, "Assessing Global Climate Change: When Will We Have Better Evidence?" *Climate Change and Energy Policy, International Conference*, October, 1991

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE

Policy-Makers Summary
July 1990

Under a Business-as-Usual Scenario of Greenhouse Gas Emissions:

- *Global Mean Temperature* will increase at a rate of 0.3°C per decade (with uncertainty range of 0.2°C to 0.5°C per decade).

  1°C above present by 2025
  3°C above present by end of next century

- Rate of increase will be uneven and will vary regionally (e.g., higher over land).

- *Global Mean Sea Level* is expected to rise 6 cm per decade (with an uncertainty range of 3 - 10 cm per decade).

  20 cm above present by 2030
  65 cm above present by end of next century

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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE

Policy-Makers Summary
July 1990

- *Global Mean Surface Temperature* has increased 0.3°C to 0.6°C over the last 100 years.
- *Global Sea Level* has risen 10 - 20 cm over same period.
- Changes not smooth with time nor uniform over the globe.
- Magnitude of change is consistent with both model predictions and natural variability.
- The *UNEQUIVOCAL DETECTION* of an enhanced greenhouse effect from observations is not likely for a decade or so.
- No firm evidence that climate has become more variable.
- Ecosystems affect and will be affected by climate change *and* increasing concetrations of CO_2.
- Gases differ in their "Global Warming Potentials."

ENVIRONMENTAL STEWARDSHIP

Global

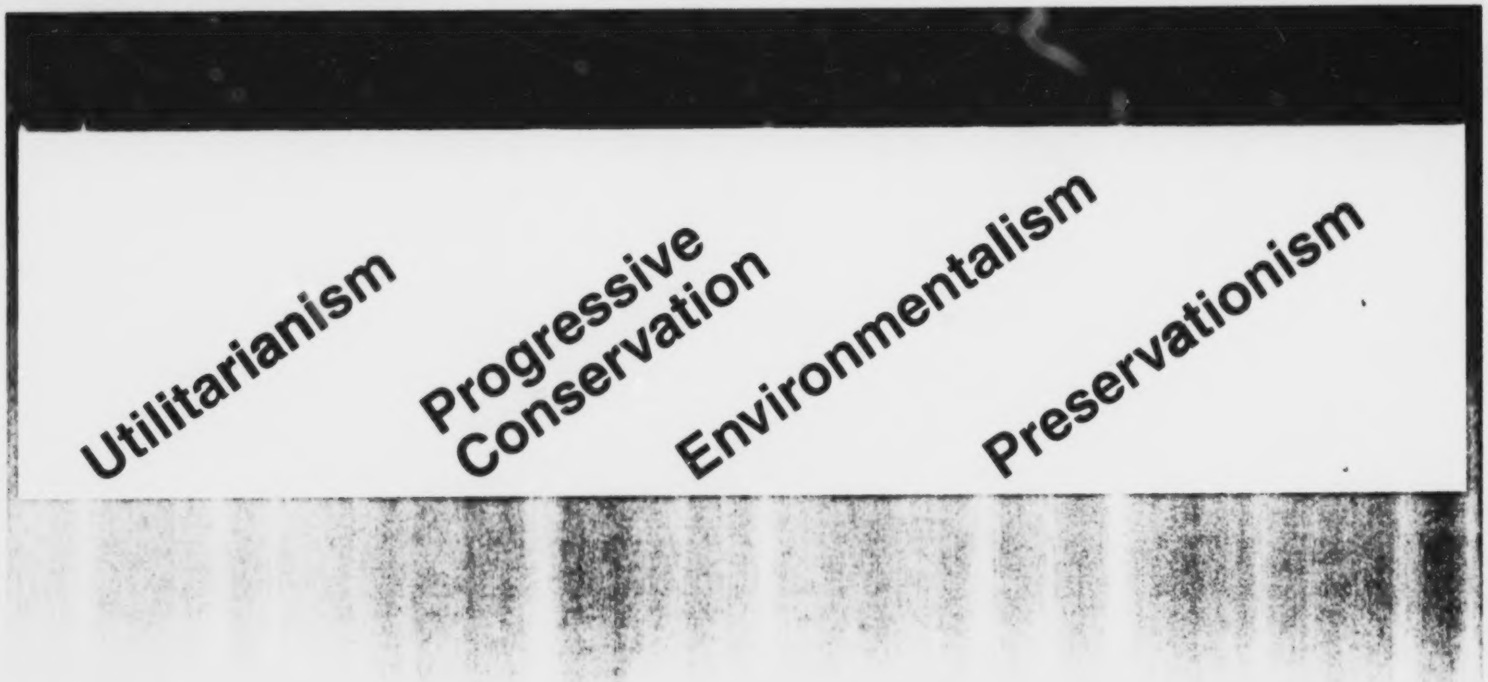
"...Fundamental to all ethics is reverence for life; to protect and encourage life is good; to destroy and demean life is bad..."
Albert Schweitzer

"...Ethical behavior is, of necessity, conscious behavior. If we are unconscious of our motives, it is unlikely that we will behave in a consistently ethical manner. If we are not aware of the particular lens through which we are looking at the world, then we do not have any true choice about what we are going to see and how we are going to respond..."
M. Scott Peck

"...A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise..."
Aldo Leopold

Earth Ethic

NATURAL RESOURCE PHILOSOPHY CONTINUUM



Utilitarianism

Progressive Conservation

Environmentalism

Preservationism

Use-Oriented

Trade-offs

Biocentric

Source: Culhane, Paul J., *Public Lands Politics*, Johns Hopkins University Press, Baltimore, MD, 1981, p. 10

VALUE ACQUISITION

- Authority
- Logic
- Senses
- Emotion
- Intuition
- "Science"

Source: Hunter Lewis: *A Question of Values* [1992]

DECISION-MAKING

Awareness

Understanding

ACTION

International Agreements Concerning CFC's

Vienna Convention

March 1985

Research and Regulatory Cooperation

No Obligation

Montreal Protocol

September 1987

1990 Freeze CFC Production at 1986 Levels

1993 20% Reduction of CFC Production

1998 50% Reduction CFC Production

May Provide Technology Transfer

May Provide International Aide Money

London Revisions

June 1990

1990 Freeze CFC Production at 1986 Levels

2000 Complete Phaseout

Will Provide Technology Transfer

$160-240 Million in International Aide for Next 3 Years

Copenhagen Revisons

1996 Complete Phaseout

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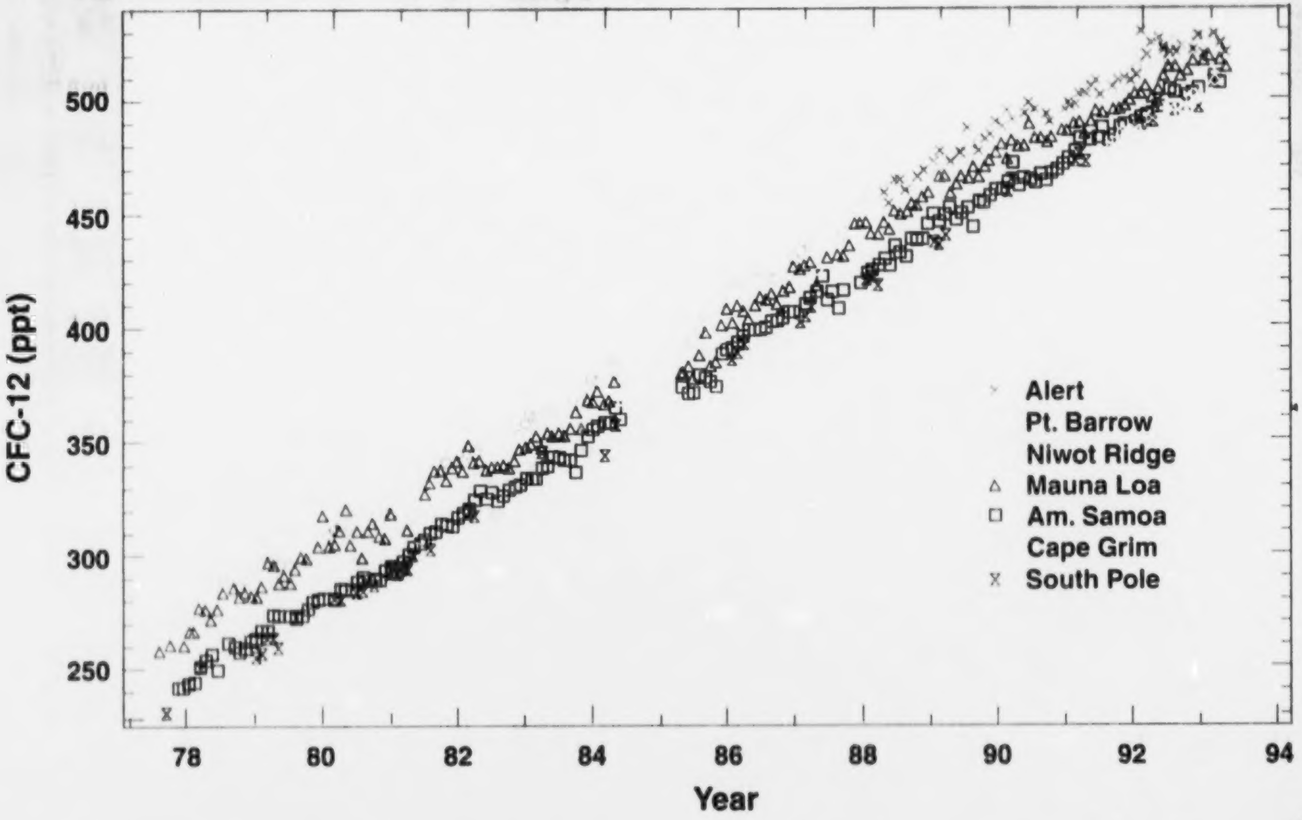
CFC-12 MEASURED MONTHLY MEANS



Monthly means reported as dry mixing ratios in parts per trillion (ppt) for chlorofluorocarbon-12 (CFC-12) at ground level for four NOAA/CMDL stations (Pt. Barrow, Alaska; Mauna Loa, Hawaii; Cape Matatula, American Samoa; and South Pole) and three cooperative stations (Alert, NWT, Canada {Atmospheric Environment Service}; Niwot Ridge, Colorado {University of Colorado}; Cape Grim Baseline Air Pollution Station, Tasmania, Australia, {Commonwealth Scientific and Industrial Research Organization}). Principal Investigators: James W. Elkins, Thayne M. Thompson and James H. Butler, NOAA/CMDL Nitrous Oxide and Halocarbons Division, Boulder, Colorado, 80303 U.S.A.; (303) 497-6224 or Internet e-mail:

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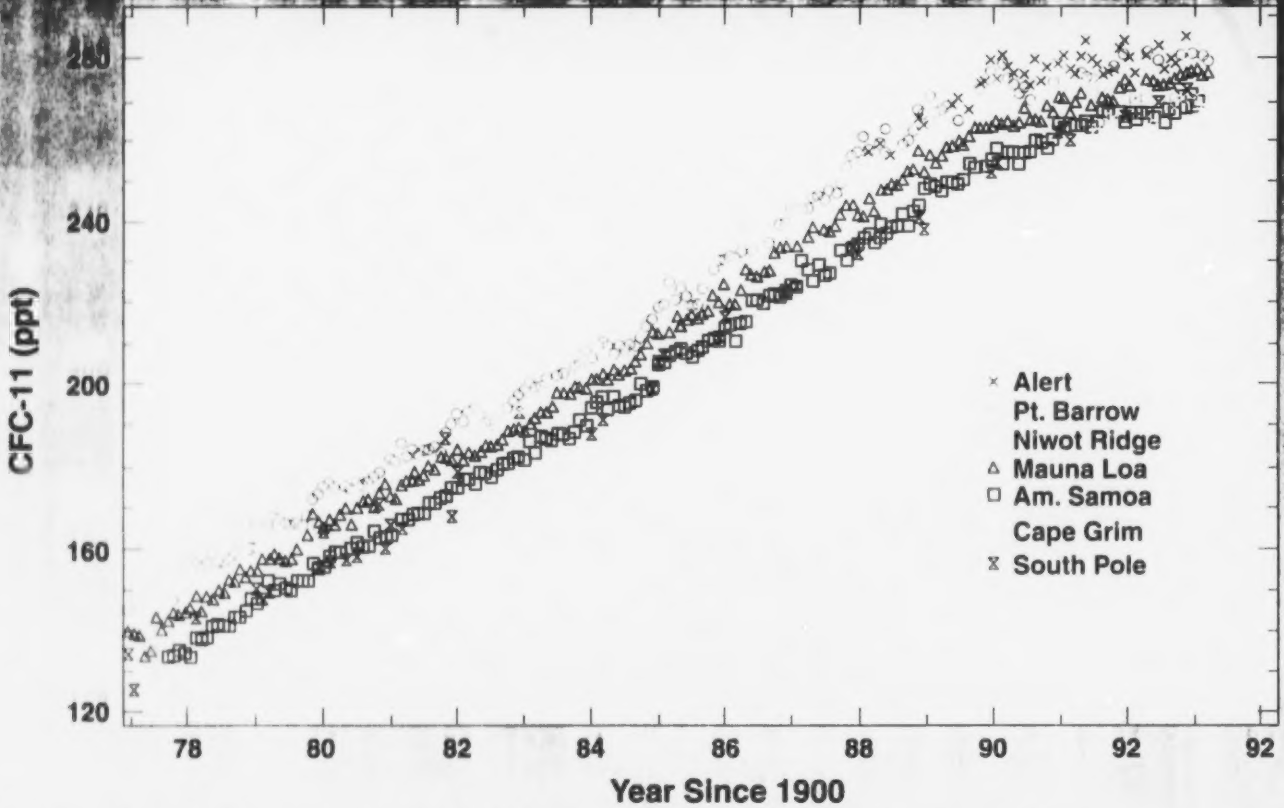
CFC-11 MEASURED MONTHLY MEANS



Monthly means reported as dry mixing ratios in parts per trillion (ppt) for chlorofluorocarbon-11 (CFC-11) at ground level for four NOAA/CMDL stations (Pt. Barrow, Alaska; Mauna Loa, Hawaii; Cape Matatula, American Samoa; and South Pole) and three cooperative stations (Alert, NWT, Canada {Atmospheric Environment Service}; Niwot Ridge, Colorado {University of Colorado}; Cape Grim Baseline Air Pollution Station, Tasmania, Australia, {Commonwealth Scientific and Industrial Research Organization}). Principal Investigators: James W. Elkins, Thayne M. Thompson and James H. Butler, NOAA/CMDL Nitrous Oxide and Halocarbons Division, Boulder, Colorado, 80303 U.S.A.; (303) 497-6224 or Internet e-mail: jelkins@cmdl.erl.gov.

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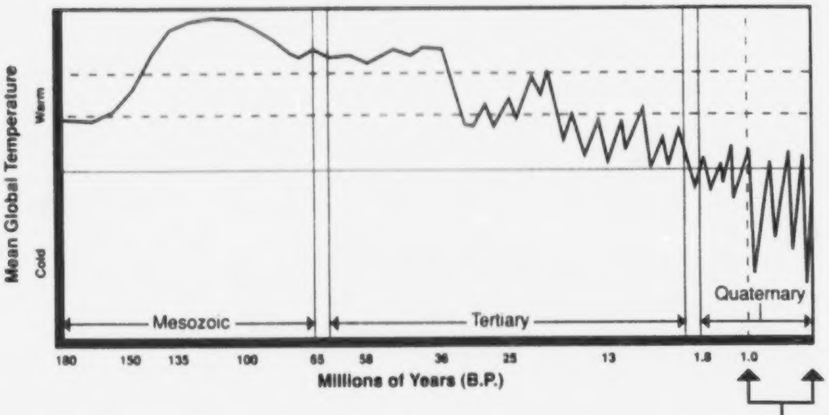
EARTHQUEST

Changes in Time in the Temperature of the Earth

Natural variability in the climate system is most often visualized in terms of the average temperature of the atmosphere near the surface of the earth, ideally for the planet as a whole. Continuous records of surface temperature sampled sufficiently over the globe to allow reconstructions of global or hemispheric averages reach back but about a hundred years, although histories of about twice that span are available for specific stations where the longest records were kept.

①



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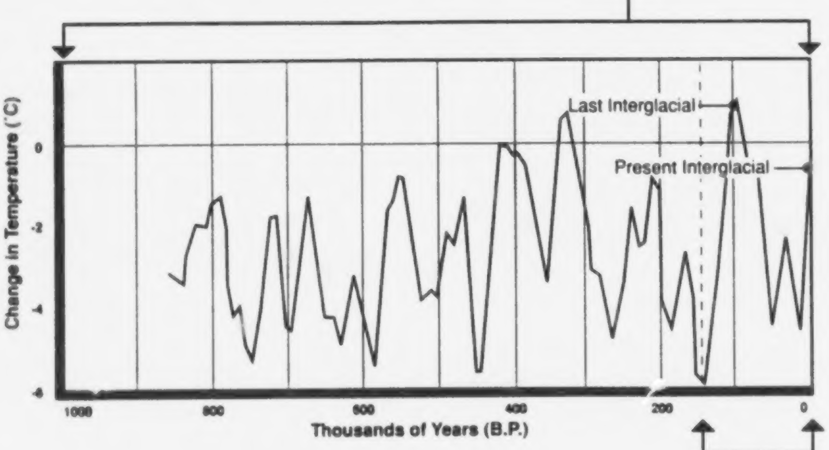
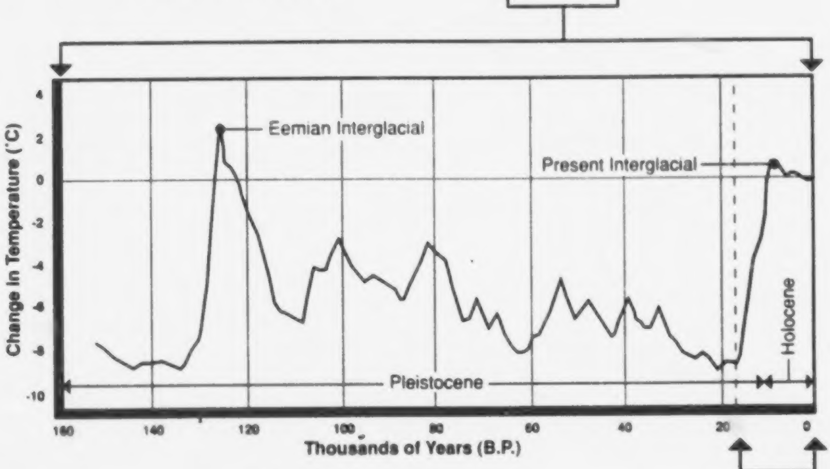


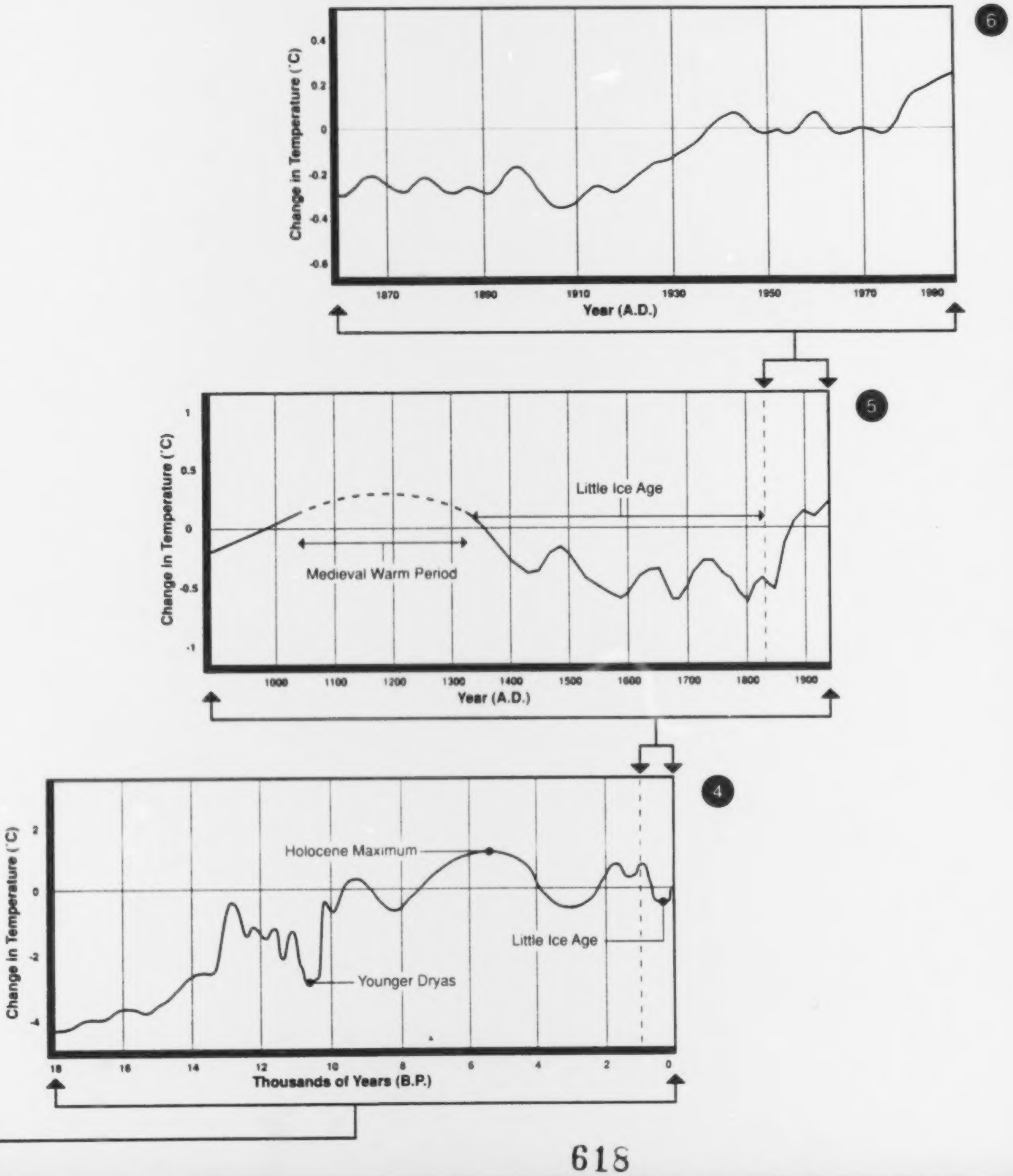
③



Reconstructions of the longer history of past variations of surface temperature are obtained through the chemical analyses of dated sediments of various kinds, and as such are themselves regionally or even site specific. One of the challenges of global change research is to improve upon what is known of past changes in temperature of the earth as a function of space and time.

A compilation representative of what is known today is shown in this set of graphs, which portray a sampling of estimated surface temperatures through the last 180 million years of earth history.

They are arranged counterclockwise from upper left in ever more recent eras and with greater and greater expansion of the time scale, as through a zoom lens. The portion delineated by a dashed line at the right edge of each of the first five graphs is expanded in the graph following it. Temperatures shown are in degrees Celsius (1°C = about 2°F), in most cases as a departure from the mean value at the turn of the present century of about 15°C (59°F). The vertical scale varies, expanding about 15 times between the first and last figures.



① Mean global temperature through the last 180 million years, derived from oxygen isotope analyses of various marine and terrestrial deposits (from L.A. Frakes, *Climates Through Geologic Time*, Elsevier, Amsterdam, 1979). The present (ca. 1900) condition, for reference, is shown as a solid horizontal line. Of note are (1) a global cooling trend since the time of the Cretaceous, when global surface temperatures were 8–10°C warmer than today, and (2) the onset of a continuing series of deeper, periodic glacial/interglacial oscillations in the latest, Quaternary period. Also shown (between dashed horizontal lines) is the range of modeled surface temperature based on a doubling of atmospheric CO_2, projecting an increase from present values of about 2–5°C (from T.J. Crowley, *Journal of Climate 3*, 1282–1292, 1990). Note that a different linear time scale is used for each of the three geologic divisions.

② Surface temperature through the last 850,000 years, derived from measurements of the ratio of ^{16}O to ^{18}O in fossil plankton which had settled to the sea floor and were recovered in a deep-sea core from the equatorial Pacific Ocean (from N.J. Shackleton and N. Opdyke, *Quaternary Research 3*, 39–55, 1973). The changes mainly reflect variations in global ice volume; the scale used here was added to show schematically the probable associated changes in global average surface temperature, based on a model-derived difference of 4–6°C between full glacial and full interglacial conditions (from W.C. Clark, *Carbon Dioxide Review*, Oxford University Press, New York, 1982). The reference line at 15°C corresponds to surface temperatures of the modern era. The glacial/interglacial oscillations, characteristic of the Pleistocene epoch, are now thought to be induced by periodic variations in the orbit of the earth and in its axis of inclination (the Milankovitch effect), which act together to bring about systematic changes in the seasonal distribution of sunlight over the surface of the planet.

③ Air temperature over Antarctica, expressed as a difference from the modern surface temperature value. These estimates are derived from hydrogen/deuterium ratios measured in an ice core from the Vostok station in Antarctica (from J. Jouzel et al., *Nature 329*, 403–408, 1987). Of note are the present (Holocene) and the preceding, somewhat warmer "Eemian" interglacial periods, each characterized by a rapid onset to an early interglacial maximum temperature, and a subsequent, slower decline. The glacial period between, called the Wisconsin glaciation in the Americas, is itself characterized by significant variations in temperature that fall systematically to a coldest extreme (maximum glaciation) about 20,000 years before the present (B.P.).

④ Variations in surface temperature, estimated from a variety of sources, principally isotope ratios from Greenland ice cores, for the last 18,000 years. The onset and subsequent character of the present interglacial or Holocene epoch are depicted. Of note are century-scale oscillations in temperature, identified in the Greenland record and in certain European lakes, during the period of deglaciation between about 15,000 and 10,000 years B.P., and a broad Holocene maximum about 5000–6000 years B.P., when summer temperatures may have been 1–2°C warmer than the present era. At these expanded scales, the temperature excursions depicted in this and the subsequent graph are the most conjectural of the set (modified from J.T. Houghton et al., *Climate Change: The IPCC Assessment*, Cambridge University Press, Cambridge, 1990).

⑤ Variations in surface air temperature estimated from a variety of sources, including temperature-sensitive tree growth indices and written records and accounts of various kinds, largely from western Europe and eastern North America. Of note is a possible protracted global warming through the Medieval period, when surface temperatures may have averaged about 0.3°C warmer than the A.D. 1900 reference. It was followed by a longer period of much colder conditions, loosely termed the Little Ice Age, when the estimated global mean temperature may have fallen about 0.6°C below the reference norm, reflecting global temperatures almost 1°C lower than the values attained during the middle of the current century (modified from J.T. Houghton et al., 1990).

⑥ Globally averaged, direct measurements of the combined sea surface temperature and air temperature over the land, shown in this case relative to 1951–80. A stepped warming of about 0.6°C is evident, qualified in the consensus 1990 IPCC Report as 0.3–0.6°C to reflect uncertainties in the data used (from J.T. Houghton et al., 1990).

Prepared by J.A. Eddy, OIES, and R.S. Bradley, University of Massachusetts. Reference: Thompson Webb III, The spectrum of temporal climatic variability, in Global Changes of the Past, *R.S. Bradley, ed., OIES, Boulder, 1991, 61-81.*

EARTHQUEST

Atmospheric Trace Gases That Are Radiatively Active and of Significance to Global Change

Atmospheric Trace Gases That Are Radiatively Active and of Significance to Global Change

The chemistry of the earth's atmosphere is a primary determinant in fixing the surface temperature and the conditions for life in general. Although the atmosphere is composed almost entirely of molecular nitrogen and oxygen, other gases that are present in only trace amounts exert significant effects, through active roles in the transfer of radiation through the air. The concentrations of many of the most active of these are changing rapidly, due to human activities. Here, for readers of *EarthQuest*, is a current summary: the first of a planned series of encapsulated information on selected earth science issues.

	Carbon Dioxide CO_2	Methane CH_4
Greenhouse Role	Heating	Heating
Effect on Stratospheric Ozone Layer	Can increase or decrease	Can increase or decrease
Principal Anthropogenic Sources	Fossil fuels; deforestation	Rice culture cattle; fossil fuels; biomass burning
Principal Natural Sources	Balanced in nature	Wetlands
Atmospheric Lifetime	50-200 yr *	10 yr
Present Atmospheric Concentration in Parts per Billion by Volume at Surface	353,000	1,720
Preindustrial Concentration (1750–1800) at Surface	280,000	790
Present Annual Rate of Increase	⇧ 0.5%	⇧ 0.9%
Relative Contribution to the Anthropogenic Greenhouse Effect	60%	15%

Notes:

* The lifetime of CO_2 in the atmosphere is calculated in two ways: one, which is relatively short (ten years), is the residence time of a single molecule before dissociation; more relevant to global change is the longer period that includes the residence time in the atmosphere-ocean system: the time that a CO_2 molecule derived from fossil fuel remains in the atmosphere-ocean system before being sequestered as terrestrial humus or deep-sea sediment. The latter is of greater value in calculating future scenarios related to greenhouse warming since it reflects the relaxation time between a cessation of all industrialized CO_2 emissions and the expected detection of a global decrease in pCO_2 (the pressure of CO_2).

† Northern Hemisphere

References:

Graedel, T.E., and P.J. Crutzen, 1990: The changing atmosphere. *In Managing Planet Earth, Readings from Scientific American Magazine*, W.H. Freeman and Co., New York.

Mitchell, J.F.B., 1989: The greenhouse effect and climate change. *Reviews of Geophysics 27*, 115-139.

Rowland, F. S., and I.S.A. Isaksen, Eds., 1988: *The Changing Atmosphere*. John Wiley and Sons, New York.

Nitrous Oxide **N_2O**	**Chlorofluorocarbons** **CFCs**	**Tropospheric Ozone** **O_3**	**Carbon Monoxide** **CO**	**Water Vapor** **H_2O**
Heating	Heating	Heating	None	Heats in air; cools in clouds
Can increase or decrease	Decrease	None	None	Decrease
Fertilizer; land use conversion	Refrigerants; aerosols; industrial processes	Hydrocarbons (with NO_x); biomass burning	Fossil fuels; biomass burning	Land conversion; irrigation
Soils; tropical forests	None	Hydrocarbons	Hydrocarbon oxidation	Evapotransporation
150 yr	60–100 yr	Weeks to months	Months	Days
310	CFC-11: 0.28 CFC-12: 0.48	20–40 †	100 †	3,000–6,000 in stratosphere
288	0	10	40–80	Unknown
⇧ 0.3%	⇧ 4%	⇧ 0.5–2.0% †	⇧ 0.7–1.0% †	Unknown
5%	12%	8%	None	Unknown

EARTHQUEST
OFFICE FOR INTERDISCIPLINARY EARTH STUDIES Spring 1993

Science Capsule

Sea-Level Rise

Illustrations and text for this science capsule were prepared by R.A. Warrick, Research Director, Centre for Environmental and Resource Studies, University of Waikato, Hamilton, New Zealand.

If you would like to receive a separate copy of this section, please contact OIES, University Corporation for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307, USA; phone: 1-303-497-1682; fax: 1-303-497-1679.

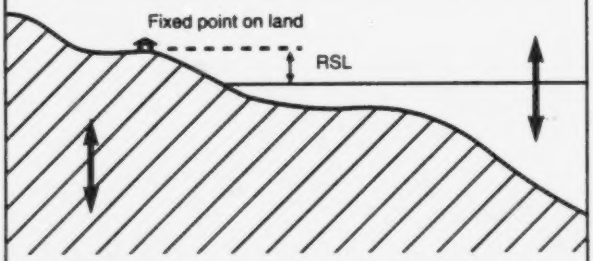
EARTHQUEST

Sea-Level Rise

A major portion of the world's population lives in coastal areas that may be vulnerable to a rise in sea level. The prospect of a rise in sea level due to global warming thus has potentially far-reaching, world-wide repercussions. For this reason, it is crucial to examine what has been happening to global sea level in the past and to estimate changes that might occur in the future.

What matters to the environment and the inhabitants of the coastal zone is *relative* sea level (RSL): the level of the ocean surface in relation to the land surface. Relative sea level can change as a result of vertical land movements, as well as changes in the level of the ocean surface itself (the latter are called *eustatic* changes). This fact has two important implications.

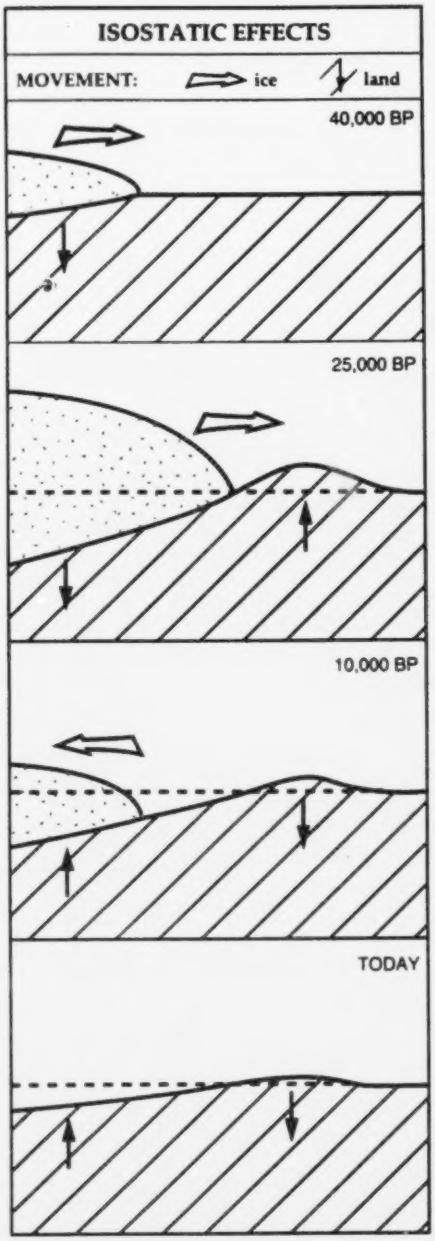
❶ CAUSES OF RELATIVE SEA-LEVEL CHANGE



Vertical Land Movement:
- isostatic adjustments
- tectonic effects
- sedimentation
- human factors (groundwater and oil extraction)

Changes in Level of Ocean Surface:
- glaciers, ice sheets
- ocean currents, tides
- hydrologic cycle changes
- expansion or contraction (steric effects)

First, both locally and regionally, various factors can cause large changes in the absolute level of the land surface, and hence in RSL. Such changes may be the result of human activities, natural geological processes, or both. As an example of human influences, RSL changes of up to about one meter per century are occurring in the U.S. Mississippi River delta, largely because people have built channels, dykes, and canals that disrupt the natural rates of sedimentation. As another example, in Bangkok, Thailand, the withdrawal of groundwater from aquifers beneath the city has allowed the land to compress and led tp local subsidence of up to 13 centimeters per year.

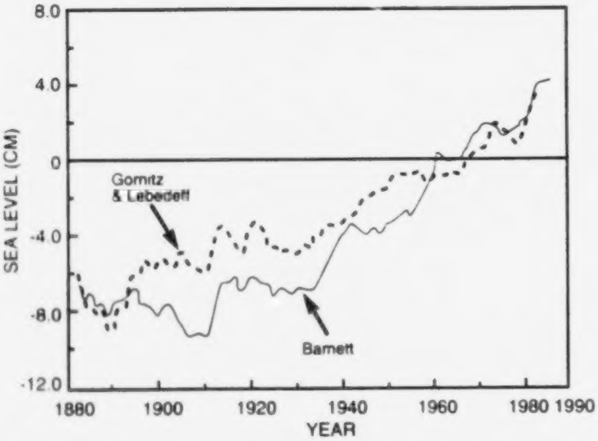


❷ Isostatic effects from the last ice age, 40,000 years before the present (BP), to today. As the ice grows and advances, it compresses the ground beneath it and pushes up the land in front of it. As the ice retreats, the compressed land springs back and the forebulge deflates.

The effects of natural geological processes are manifest, for example, in high-latitude areas of Europe and North America, where the land surface is still rising after the removal of the large continental ice sheets that covered these regions during the last glacial period. This process is referred to as *isostatic rebound*. As a result of this effect, RSL is falling by up to one meter per century in parts of the Hudson's Bay region. Also, along the nonglaciated parts of the U.S. East Coast, isostatic effects are still causing RSL to rise as the *forebulge*, created in front of the last glaciation's advancing ice sheet, continues to deflate. Here, subsiding land threatens to exacerbate any eustatic rise in sea level due to global warming.

The second implication of the twofold nature of RSL changes is that it complicates the search for global sea-level trends. Tide gauge records are the only viable data source for identifying 20th-century trends in global mean sea level. A tide gauge, being located at the land/sea interface, measures sea level in relation to a fixed benchmark on the land—and thus dutifully records vertical land movements as well as eustatic ocean surface movements. In the search for global trends, the land component must somehow be removed. There are no foolproof methods for doing this. Thus, estimates of recent changes in global sea level derived from tide gauge records remain subject to considerable uncertainty.

Nevertheless, there is widespread agreement within the scientific community that global sea level has risen over the last 100 years. The best estimates lie in the range of 10–20 centimeters, although faster or slower rates of rise (including zero rise, albeit with low probability) cannot be ruled out. The rise is probably related to the approximately 0.5°C global warming that has occurred over the same period. The most likely climate-related causes of this change—and, consequently, of a future change—are twofold: thermal expansion of the oceans, and changes in the volume of land-based ice, that is, the ice sheets of Antarctica and Greenland and the many smaller ice caps and mountain glaciers.



❶ Sea-level rise over the last century. The baseline is obtained by setting the average for the period 1951–70 to zero.

Thermal Expansion

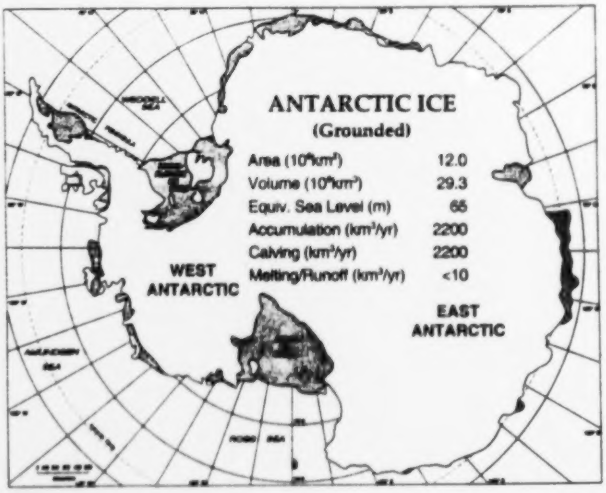
As the oceans warm, they expand. This is because the volume occupied by sea water is inversely related to its density (lower density means larger volume) and the density is affected by temperature. Sea water has a maximum density around 0°C; as temperature rises, its density decreases, and it therefore expands. Ocean volume (and sea-level) changes associated with changes in density are called *steric* changes. Thermal expansion is the most important such process. Judging from model results (direct observations are meager), oceanic thermal expansion may have accounted for around one-half of the observed rise in sea level over the last 100 years.

Melting of Land-Based Ice

Increased melting of land-based ice could also cause sea level to rise. (Note that the melting of floating ice, such as Arctic sea ice, will not noticeably affect sea level, just as the melting of an ice cube in a glass of water does not change the level of water in the glass.) Oddly, in the short term (decades to a century), it is the source with the least ice—the smaller ice caps and mountain glaciers, which contain less than 1% of the world's total land-based ice—that could contribute the most to sea-level rise as the world warms. Due to their climatic and topographic circumstances, many of the smaller glaciers of the world are acutely sensitive to changes in climate, particularly in temperature. On average, the glaciers of the world have been melting during the 20th century as the global temperature has risen. But there is a limit to their potential contribution to sea-level rise; the smaller glaciers contain only enough water to make the sea rise 30–60 centimeters.

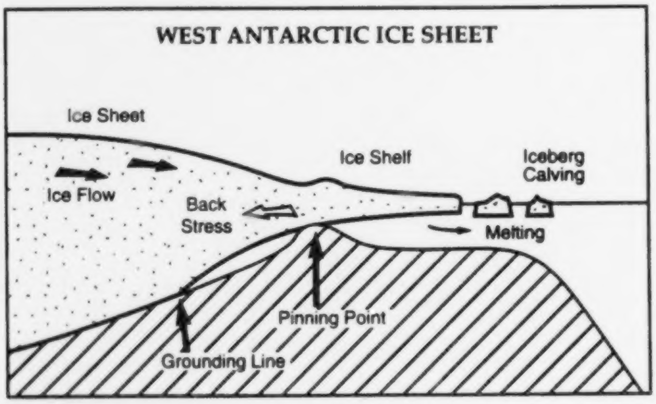
On the decadal time scale, the ponderous Antarctic ice sheet is not expected to contribute to a rise in sea level; rather, just the opposite. Ice is lost from the Antarctic ice sheet by flowing (in ice streams) to the sea, where it breaks off (*calves*) to form icebergs. Very little ice is lost directly from melting because the climate is too cold, and would remain too cold even under most projections of global warming for the next century. It is true that the rate of calving depends on the dynamics of ice flow, which, in turn, is affected by climate. However, the dynamic response of the ice sheet to a change of climate is slow, on the order of thousands of years, so calving rates are unlikely to increase in the short term. A warming around Antarctica would, however, immediately increase the atmospheric moisture content and (most probably) precipitation. Thus, the snow and ice accumulation rate is likely to increase. By itself, this would lead to a decrease in global mean sea level.

On the century time scale, one dynamic response has received much attention, namely, the possible surging of the West Antarctic ice sheet. This consists of a large marine ice sheet grounded well below sea level and a large floating ice shelf that, through shear along "pinning points" and lateral margins, exerts back pressure (or back stress) on the grounded mass. Because of its unique position, some scientists have argued that this part of Antarctica may be more sensitive to warming. Their concern is that warmer ocean currents could cause a thinning of the ice shelf and/or increase in calving rates, leading to a weakening of back stress on the main ice sheet. This, it is feared, would accelerate the rate of ice flow across the grounding line and raise sea level. There is, however, great uncertainty about the magnitude of this effect. It is unlikely to play a large role over the next century, but it could be important on longer time scales if global warming becomes sufficiently large.



Area ($10^6 km^2$)	12.0
Volume ($10^6 km^3$)	29.3
Equiv. Sea Level (m)	65
Accumulation (km^3/yr)	2200
Calving (km^3/yr)	2200
Melting/Runoff (km^3/yr)	<10

The Antarctic ice sheet. (Gray areas are not covered by the ice sheet.)



Processes in the West Antarctic ice sheet.

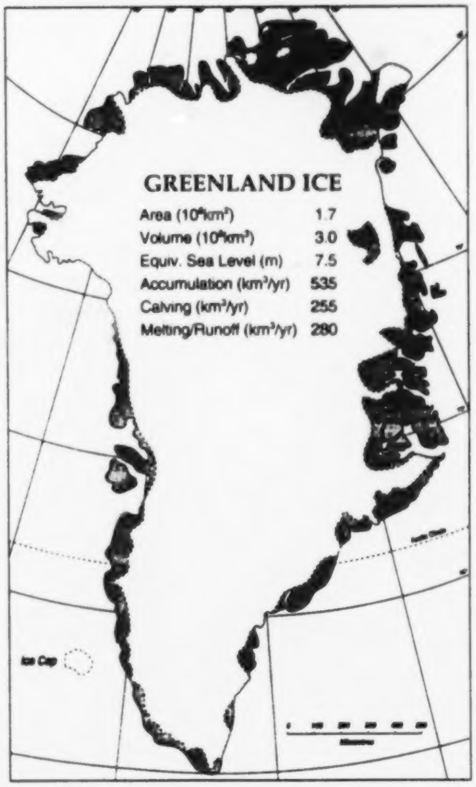
Sea-Level Rise (continued)

The smaller Greenland ice sheet is located in a warmer climate and would respond quite differently from Antarctica. In Greenland, the rate of direct melting is approximately equal to that of calving. While a warming in Greenland would not be expected to increase calving rates in the short term (for the same reason as for Antarctica), it would increase the melting rate. Moreover, it is likely that the enhanced melting rate would more than offset higher precipitation and accumulation rates in the higher reaches of the ice sheet. The net effect would be to decrease the Greenland ice mass and raise sea level.

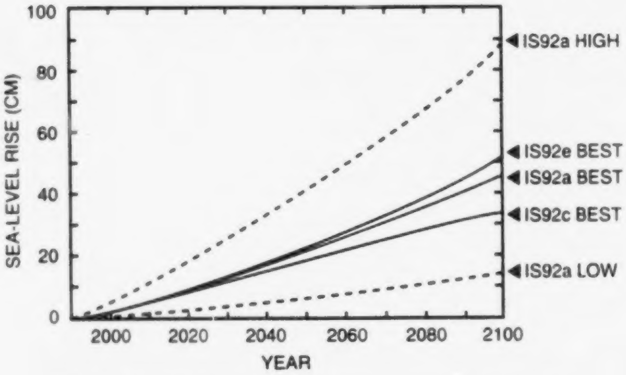
How High, How Quickly?

On the whole, global warming is likely to cause global sea level to rise. The issue is, how rapidly, and by how much? Several recent projections of the global mean eustatic component of future sea-level rise have been made using the Intergovernmental Panel on Climate Change (IPCC) scenarios of future greenhouse gas emissions. In its 1990 report, the IPCC, using "best-estimate" climate and sea-level models, estimated that the rise over 1990–2100 would be around 66 centimeters under existing policies (that is, using the IPCC's "business-as-usual" emissions scenario). When model uncertainties were accounted for, the range was 31–110 centimeters.

In 1992, the IPCC produced a set of revised emissions scenarios, all of which corresponded to the business-as-usual assumption. These scenarios attempted to allow for uncertainties in emissions arising from the uncertainties in projections of future population change, energy usage, etc. For the central emissions scenario (known as IS92a), recent calculations give a 1990–2100 sea-level rise of 46 centimeters for best-guess modeling, substantially lower than the earlier best-guess estimate. The model uncertainties lead to a range of 14–88 centimeters. This uncertainty must be added to that arising from uncertainties in future emissions (illustrated in Figure 7), so the overall range of possibilities is very large. Nevertheless, these estimates suggest a rate of sea-level rise that is still two to four times higher than that experienced over the last 100 years—a rate that will almost certainly prove worrisome to the millions of inhabitants of low-lying coastal plains, river deltas, coral islands, and other vulnerable coastal locations of the world.



⑥ The Greenland ice sheet. (Gray areas are not covered by the ice sheet.)



⑦ Predicted sea-level rise according to various IPCC emissions scenarios. The five scenarios developed by the IPCC in 1992 were designated IS92a, b, c, d, e, and f. IS92c gives the lowest and IS92e gives the highest emissions. The range between IS92a high, best, and low versions is the result of modeling uncertainties.

Information Sources

The most recent international review of predicted sea-level rise is the chapter by R.A. Warrick and J. Oerlemans (with contributions from 13 other scientists) in the 1990 IPCC report, *Climate Change: The IPCC Scientific Assessment* (J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds.), Cambridge University Press, 1990. The historical sea-level data given in Figure 3 come from T.P. Barnett, "Global sea level change," in NCPO, *Climate Variations over the past Century and the Greenhouse Effect*, National Climate Program Office/National Oceanic and Atmospheric Administration, Rockville, Maryland, 1988; and V. Gornitz and S. Lebedeff, "Global sea level changes during the past century," in *Sea-Level Fluctuation and Coastal Evolution* (D. Nummedal, O.H. Pilkey, and J.D. Howard, eds.), SEPM Special Publication No. 41, 1987, pp. 3–16. Results based on the 1992 IPCC emissions scenarios are given in T.M.L. Wigley and S.C.B. Raper, "Implications for climate and sea level of revised IPCC emissions scenarios," *Nature* Vol. 357, 1992, pp. 293–300. The results presented in Figure 7 are an updated version of those published in *Nature*, kindly provided by S. Raper. For a comprehensive overview of the subject, see *Climate and Sea Level Change: Observations, Projections and Implications* (R.A. Warrick, E.M. Barrow, and T.M.L. Wigley, eds.), Cambridge University Press, 1993.

EARTHQUEST

OFFICE FOR INTERDISCIPLINARY EARTH STUDIES Fall 1991

Science Capsule

This pull-out section is part of an *EarthQuest* series of illustrated capsule reviews of scientific topics related to global change research. This section is printed in a form that can be easily reproduced for classroom or other uses. Illustrations and text for this issue's capsule review were prepared by Dan Albritton and Susan Solomon of the National Oceanic and Atmospheric Administration.

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EARTHQUEST

The Ozone Layer and Homo Sapiens

o·zone (ō zōn) *n.* [G. pr. part. of *ozein,* to smell]

Ozone is a pungent gas naturally present in small amounts at ground level and in much larger abundance in the stratosphere, where it forms a layer that plays a critical role in the earth's ecological balance. Ozone is produced from atmospheric oxygen by the action of sunlight. In turn, ozone absorbs certain kinds of ultraviolet light that are potentially harmful to living things. Life as we know it on the planet's surface is possible in part because of the protection afforded by the stratospheric ozone layer.

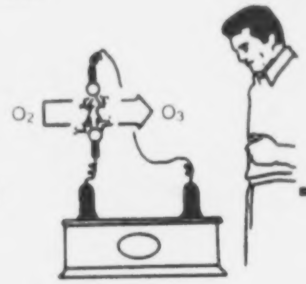
Since the discovery of ozone and the recognition of its unique importance to life, much has been learned about the nature and chemistry of this atmospheric component. Gradually it has become clear that the ozone layer can be affected all too easily by other molecules, some of which are products of human activity.

Chlorofluorocarbons, once thought to be miracle compounds completely benign to their environment, are now recognized as ozone destroyers. Scientific evidence has established that large-scale ozone losses over the Antarctic are caused by these compounds.

Recognizing this problem, many nations have taken collective action to eliminate the production and use of the most harmful of these compounds. Industry is seeking safe substitutes.

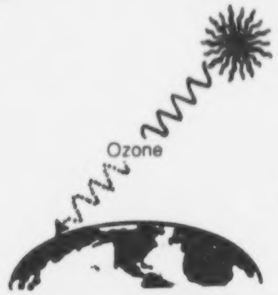
This timeline depicts the history of ozone—its science and its relationship to mankind—from its discovery in 1840 to the present.

1840



① Ozone Discovered

1880

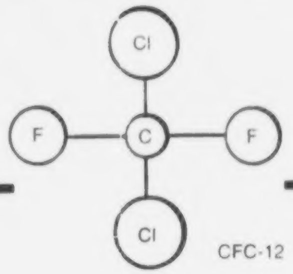


② UV-Ozone Cutoff Discovered

Late 1920s

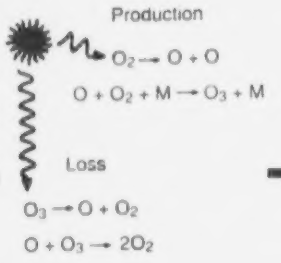
③ Ozone and Meteorology

1928


Cl
F
C
F
Cl
CFC-12

④ CFCs Invented

1930

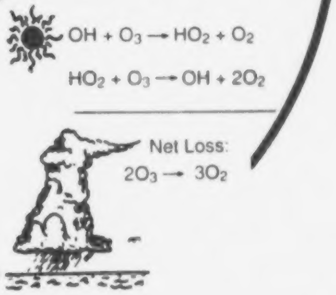

Production
$O_2 \rightarrow O + O$
$O + O_2 + M \rightarrow O_3 + M$
Loss
$O_3 \rightarrow O + O_2$
$O + O_3 \rightarrow 2O_2$

⑤ Pure Oxygen Chemistry

1950s

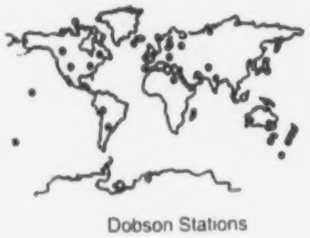
⑥ CFC Usage Grows

1950s


$OH + O_3 \rightarrow HO_2 + O_2$
$HO_2 + O_3 \rightarrow OH + 2O_2$
Net Loss:
$2O_3 \rightarrow 3O_2$

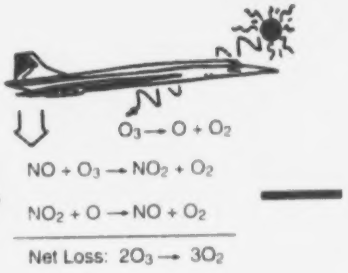
⑦ Hydrogen-Ozone Chemistry

1957


Dobson Stations

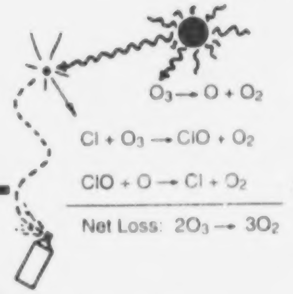
⑧ The International Geophysical Year

1970


$O_3 \rightarrow O + O_2$
$NO + O_3 \rightarrow NO_2 + O_2$
$NO_2 + O \rightarrow NO + O_2$
Net Loss: $2O_3 \rightarrow 3O_2$

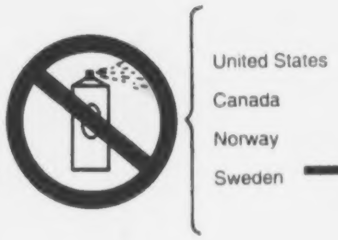
⑨ Nitrogen-Ozone Chemistry

1974


$O_3 \rightarrow O + O_2$
$Cl + O_3 \rightarrow ClO + O_2$
$ClO + O \rightarrow Cl + O_2$
Net Loss: $2O_3 \rightarrow 3O_2$

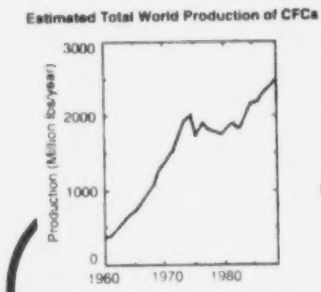
⑩ Chlorine-Ozone Chemistry

1979


United States
Canada
Norway
Sweden

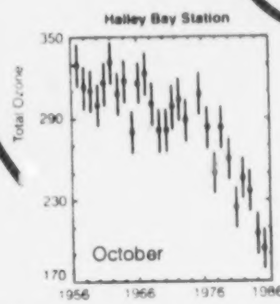
⑪ CFC Aerosol Ban

1980s



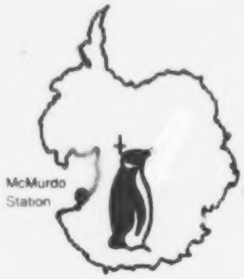
⑫ CFC Usage Grows Again

1985



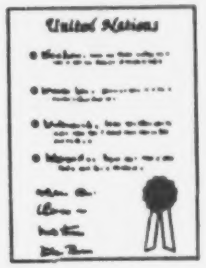
⑬ Ozone Hole Discovered

1986


McMurdo Station

⑭ National Ozone Expedition (NOZE)

1987


United Nations

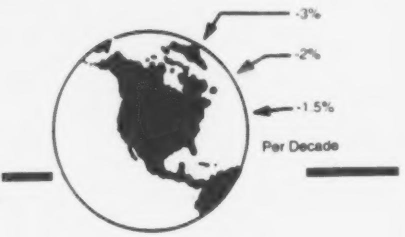
⑮ Montreal Protocol Signed

1987

Punta Arenas, Chile

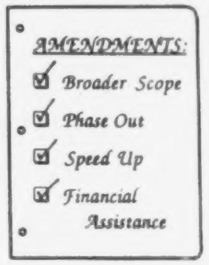
⑯ Airborne Antarctic Ozone Experiment (AAOE)

1988


-3%
-2%
-1.5%
Per Decade

⑰ Ozone Depletion Not Confined to Antarctica

1990


AMENDMENTS:
☑ Broader Scope
☑ Phase Out
☑ Speed Up
☑ Financial Assistance

⑱ Montreal Protocol Amended

1990

Clean Air Act Amendments of 1990

⑲ U.S. Clean Air Act Amendments of 1990

BEST COPY AVAILABLE

① **Ozone Discovered.** A letter entitled "Research on the nature of the odor in certain chemical reactions" was presented to the Academie des Sciences in Paris by C.F. Shoenbein in 1840. Shoenbein was unable to determine the origin of the chemical species that he had found or to characterize its structure, but named the mysterious pungent-smelling molecule "ozone." A few years later, J.L. Soret identified the compound as O_3.

② **UV-Ozone Cutoff Discovered.** In 1879–81, W.N. Hartley and A. Cornu measured the ultraviolet radiation reaching the surface of the earth and found a sharp cutoff, which they correctly attributed to ozone. These pioneering measurements also showed that the bulk of the ozone must be in the upper atmosphere rather than near ground level. The ozone layer had been discovered.

③ **Ozone and Meteorology.** During the late 1920s, G.M.B. Dobson and his colleagues presented the first systematic measurements of the distribution and variability of the ozone layer. While it might be anticipated that ozone's production by the action of sunlight on oxygen would lead to a tropical maximum, the measurements revealed the surprising result of a maximum during spring at high latitudes. Dobson correctly concluded that stratospheric winds must play an important role in transporting ozone around the globe. Thus, via ozone studies he formulated a general picture of the circulation of the stratosphere that has endured largely unchanged into contemporary scientific thought.

④ **CFCs Invented.** In 1928, an industrial chemist named T. Midgley was asked to develop a nonflammable, nontoxic compound to replace the hazardous compounds (such as ammonia) then used in home refrigerators. Within two days, he selected a chlorofluorocarbon (CFC) as the ideal refrigerant. In a dramatic demonstration of its complete safety for living things, Midgley personally inhaled the compound.

⑤ **Pure Oxygen Chemistry.** In 1930, S. Chapman presented the first theory of ozone chemistry. He postulated a simple three-step mechanism involving production of atomic oxygen via sunlight, followed by reaction of atomic oxygen with oxygen molecules (in the illustration, "M" indicates any molecule) to produce ozone, in chemical balance with destruction via the reaction of atomic oxygen and ozone. This series of "oxygen-only" reactions became known as the Chapman cycle and broadly explained why the ozone layer forms at stratospheric altitudes.

⑥ **CFC Usage Grows.** During the 1950s, chlorofluorocarbons came into widespread use in a variety of applications, particularly for refrigeration and later in air conditioning, spray cans, and foams, and as solvents. The chlorofluorocarbons were hailed as miracle chemicals.

⑦ **Hydrogen-Ozone Chemistry.** Scientific studies in the 1950s began to reveal that the pure oxygen chemistry envisioned by Chapman was not sufficient to explain the observed distribution of atmospheric ozone. In the mid-1960s, J. Hampson postulated a series of reactions involving hydrogen compounds produced from water vapor that are capable of rapidly destroying ozone. It became clear that the chemistry that establishes the ozone layer is dependent upon more than just oxygen.

⑧ **The International Geophysical Year.** The IGY in 1957 was marked by intense international research programs on the earth and its environment. A network of ground-based instruments for continuous monitoring of ozone using the technique pioneered by Dobson was established worldwide (the Dobson network). The one installed by the British Antarctic Survey at their remote site at Halley Bay, Antarctica, was to play a fateful role in the interaction of humankind and the ozone layer.

⑨ **Nitrogen-Ozone Chemistry.** Concern about the possible use of supersonic transport planes led to the discovery of an ozone-destroying catalytic cycle involving nitrogen compounds by P. Crutzen and H.S. Johnston in 1970–71. Although the initial projections of large ozone decreases due to these aircraft were later shown to be excessive, the discovery revealed yet another chemical mechanism for rapid ozone loss. It also provided the first stimulus to public awareness regarding the importance and fragility of the ozone layer.

⑩ **Chlorine-Ozone Chemistry.** Measurements taken in the early 1970s revealed a growing abundance of chlorofluorocarbons at ground level, prompting M. Molina and F.S. Rowland to wonder where exactly these miracle chemicals end up. They studied the problem in detail and concluded that their eventual fate must be to rise up into the stratosphere, break down, and begin to destroy the ozone layer in like manner to the action of hydrogen and nitrogen. While hydrogen and nitrogen compounds are naturally produced in large quantities in addition to manmade contributions, the chlorine perturbation was recognized as potentially more disturbing, since the natural source of chlorine to the atmosphere is small.

⑪ **CFC Aerosol Ban.** Theoretical calculations suggested that continuing use of CFCs might cause about a 5% depletion of the ozone layer in 100 years or so. Concern over the possible future depletion of the earth's ozone layer by the action of chlorofluorocarbons led the United States, Canada, Norway, and Sweden to ban their use in nearly all spray cans in their countries. Global use of chlorofluorocarbons slowed significantly.

⑫ **CFC Usage Grows Again.** Chlorofluorocarbon use began to increase again in the early 1980s, due in part to their use as cleaning agents in the rapidly expanding electronics industry. Home insulation and foam-blowing applications were also booming. Growing populations and worldwide industrial development created an expanding market.

⑬ **Ozone Hole Discovered.** In 1985, scientists from the British Antarctic Survey reported their observations of a deepening depletion in the springtime ozone layer above Halley Bay, Antarctica. Their work was quickly confirmed by measurements from satellites and from other Antarctic research stations, including the South Pole (United States) and Syowa (Japan). The phenomenon became known as the "ozone hole." The observed change in ozone was about 40% in 1985, as compared to projections of about 5% in 100 years, raising fears that ozone depletion may have been drastically underestimated.

⑭ **National Ozone Expedition (NOZE).** In response to the discovery of the ozone hole, a National Ozone Expedition was dispatched to McMurdo Station, Antarctica, from August to November 1986. A series of ground-based and balloon-borne measurements were carried out that pointed toward chlorine and bromine compounds as the likely cause of the ozone hole.

⑮ **Montreal Protocol Signed.** On 16 September 1987, the United Nations adopted the Montreal Protocol on Substances that Deplete the Ozone Layer. It required a freeze on the annual use of CFCs as early as 1990, with decreases leading to a 50% reduction by the year 2000. A freeze on halon annual production would occur in 1993. Progress in science and technology would set the pace for future changes in the provisions.

⑯ **Airborne Antarctic Ozone Experiment (AAOE).** In August–September 1987, a series of high-flying aircraft flights probed the stratosphere from South America to Antarctica under AAOE. This sequence of direct measurements clearly confirmed that chlorine and bromine compounds were the primary agents responsible for the Antarctic ozone hole.

⑰ **Ozone Depletion Not Confined to Antarctica.** Observations of trends from ozone measurement stations worldwide along with satellite data were carefully analyzed by an international group of experts in 1988. They came to the alarming conclusion that ozone decreases that could not be explained by known natural effects were already occurring not only in Antarctica, but also in the Northern Hemisphere midlatitudes and in the Arctic. Moreover, the decreases were larger than what could be explained by the current global models.

⑱ **Montreal Protocol Amended.** The participating countries are required to periodically assess the adequacy of the protocol's provisions in light of new scientific and technical advances. Because CFCs and halons were identified as the cause of the Antarctic ozone hole and in view of the downward trends in global ozone, the contracting parties substantially strengthened the protocol. The new provisions broadened the scope of the chemicals that are controlled, called for accelerated reductions in emissions, and required complete phaseout of CFCs, halons (except essential uses), and other major ozone-depleting substances by the turn of the century.

⑲ **U.S. Clean Air Act Amendments of 1990.** While the Clean Air Act focuses mainly on urban pollution and acid rain, it also addresses the protection of the ozone layer. Because of recent scientific findings, Congress enacted amendments that are even more stringent than the updated Montreal Protocol. Notably, these include requirements for recycling CFCs and limitations on the time that CFC replacements can be used. The Clean Air Act also recognized that progress in research is essential and requires periodic reports on the health of our ozone shield.

Historical Landsat Data Comparisons

Illustrations of the Earth's Changing Surface

U.S. Department of the Interior
U.S. Geological Survey

Historical Landsat Data Comparisons

Illustrations of the Earth's Changing Surface

March 1995

U.S. Department of the Interior
U.S. Geological Survey
EROS Data Center

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Introduction

The U.S. Geological Survey's (USGS) EROS Data Center (EDC) has managed the Landsat data archive for more than two decades. This archive provides a rich collection of information about the Earth's land surface. Major changes to the surface of the planet can be detected, measured, and analyzed using Landsat data. The effects of desertification, deforestation, pollution, cataclysmic volcanic activity, and other natural and anthropogenic events can be examined using data acquired from the Landsat series of Earth-observing satellites. The information obtainable from the historical and current Landsat data play a key role in studying surface changes through time.

This document provides an overview of the Landsat program and illustrates the application of the data to monitor changes occurring on the surface of the Earth. To reveal changes that have taken place within the past 20 years, pairs and triplicates of images were constructed from the Landsat multispectral scanner (MSS) and thematic mapper (TM) sensors. Landsat MSS data provide a historical record of the Earth's land surface from the early 1970's to the early 1990's. Landsat TM data provide land surface information from the early 1980's to the present.

A Brief History of the Landsat Program

The concept of a civilian Earth resources satellite was conceived in the Department of Interior in the mid-1960's. The National Aeronautics and Space Administration (NASA) embarked on an initiative to develop and launch the first Earth monitoring satellite to meet the needs of resource managers and Earth scientists. The USGS entered into a partnership with NASA in the early 1970's to assume responsibility for data archiving and distribution of data products. On July 23, 1972, NASA launched the first in a series of satellites designed to provide repetitive global coverage of the Earth's land masses. Designated initially as the Earth Resources Technology Satellite-A (ERTS-A), it used a Nimbus-type platform that was modified to carry sensor systems and data relay equipment. When operational orbit was achieved, it was designated ERTS-1. The satellite continued to function beyond its designed life expectancy of 1 year and finally ceased to operate on January 6, 1978, more than 5 years after its launch date. The second in this series of Earth resources satellites (designated ERTS-B) was launched January 22, 1975. It was renamed Landsat 2 by NASA, which also renamed ERTS-1 to Landsat 1. Three additional Landsats were launched in 1978, 1982, and 1984 (Landsats 3, 4, and 5 respectively). Each successive satellite system had improved sensor and communications capabilities (table 1).

NASA was responsible for operating the Landsats through the early 1980's. In January 1983, operations of the Landsat system were transferred to the National Oceanic and Atmospheric Administration (NOAA). In October 1985, the Landsat system was commercialized and the Earth Observation Satellite Company assumed responsibility for its operation. Throughout these changes, the EDC retained primary responsibility as the Government archive of Landsat data. The Land Remote Sensing Policy Act of 1992 (Public Law 102-555) officially authorized the National Satellite Land Remote Sensing Data Archive and assigned responsibility to the Department of the Interior. In addition to its Landsat data management responsibility the EDC investigates new methods of characterizing and studying changes on the land surface with Landsat data.

Table 1

Background information and status of Landsat satellites

Satellite	Launched	Decommissioned	Sensors
Landsat 1	July 23, 1972	January 6, 1978	MSS and RBV
Landsat 2	January 22, 1975	February 25, 1982	MSS and RBV
Landsat 3	March 5, 1978	March 31, 1983	MSS and RBV
Landsat 4	July 16, 1982	*	TM and MSS
Landsat 5	March 1, 1984	**	TM and MSS
Landsat 6	October 5, 1993	***	ETM
Landsat 7	Fall 1998****		ETM +*****

* in standby mode
** operational
*** never achieved orbit
**** anticipated launch
***** The sensor onboard Landsat 6 was called the enhanced thematic mapper (ETM). Landsat 7 will carry the enhanced thematic mapper plus (ETM+).

Characteristics of the Landsat System

Landsats 1 through 3 operated in a near-polar orbit at an altitude of 920 km with an 18-day repeat coverage cycle. These satellites circled the Earth every 103 minutes, completing 14 orbits a day (fig. 1). Eighteen days and 251 overlapping orbits were required to provide nearly complete coverage of the Earth's surface with 185 km wide image swaths. The amount of swath overlap or sidelap varies from 14 percent at the Equator to a maximum of approximately 85 percent at 81° north or south latitude (fig. 2). These satellites carried two sensors: a return beam vidicon (RBV) and a MSS. The RBV sensor was essentially a television camera and did not achieve the popularity of the MSS sensor. The MSS sensor scanned the Earth's surface from west to east as the satellite moved in its descending (north-to-south) orbit over the sunlit side of the Earth. Six detectors for each spectral band provided six scan lines on each active scan. The combination of scanning geometry, satellite orbit, and Earth rotation produced the global coverage necessary for studying land surface change (fig. 3). The resolution of the MSS sensor was approximately 80 m with radiometric coverage in four spectral bands from the visible green to the near-infrared (IR) wavelengths (table 2). Only the MSS sensor on Landsat 3 had a fifth band in the thermal-IR.

Landsats 4 and 5 carry both the MSS and the TM sensors; however, routine collection of MSS data was terminated in late 1992. They orbit at an altitude of 705 km and provide a 16-day, 233-orbit cycle with a swath overlap that varies from 7 percent at the Equator to nearly 84 percent at 81° north or south latitude. These satellites were also designed and operated to collect data over a 185 km swath. The MSS sensors aboard Landsats 4 and 5 are identical to the ones that were carried on Landsats 1 and 2. The MSS and TM sensors primarily detect reflected radiation from the Earth in the visible and IR wavelengths, but the TM sensor provides more radiometric information than the MSS sensor. The wavelength range for the TM sensor is from the visible (blue), through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum (table 3). Sixteen detectors for the visible and mid-IR wavelength bands in the TM sensor provide 16 scan lines on each active scan. Four detectors for the thermal-IR band provide four scan lines on each active scan. The TM sensor has a spatial resolution of 30 m for the visible, near-IR, and mid-IR wavelengths and a spatial resolution of 120 m for the thermal-IR band.

All of the Landsats have been in sun-synchronous orbits with equatorial crossing times ranging from 8:30 a.m. for Landsat 1 to 9 a.m. for Landsat 2 to the current time of 9:45

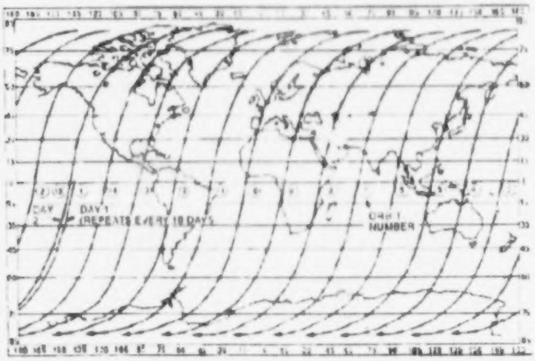


Figure 1. Typical daily orbit pattern for Landsats 1 through 3 (from Landsat Data Users Handbook, 1979, USGS).

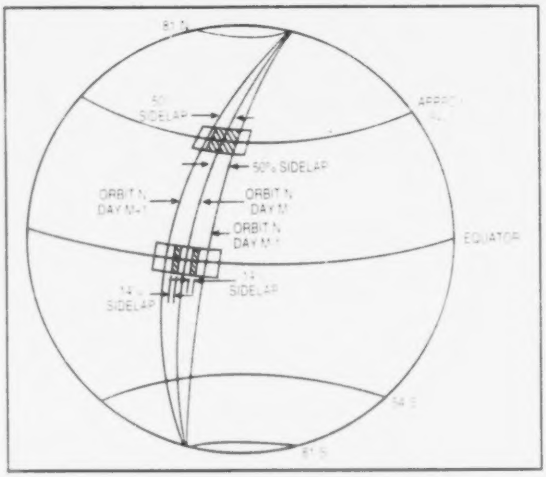


Figure 2. Poleward increase of sidelap between adjacent tracks of Landsats 1 through 3 (from Landsat Data Users Handbook, 1979, USGS).

a.m. for Landsat 5, and the proposed time of 10 a.m. for Landsat 7.

Characteristics of Landsat Data

Since 1972 these satellites have provided repetitive, synoptic, global coverage of high-resolution multispectral imagery. The characteristics of the MSS and TM bands were selected to maximize their capabilities for detecting and monitoring different types of Earth's resources. For example, MSS band 1 (band 2 of TM) can detect green reflectance from healthy vegetation, and band 2 of MSS (band 3 of TM) is designed for detecting chlorophyll absorption in vegetation. MSS bands 3 and 4 (TM band 4) are ideal for near-IR reflectance peaks in healthy green vegetation and for detecting water-land interfaces. TM band 1 can penetrate water for bathymetric mapping along coastal areas and is useful for soil-vegetation differentiation and for distinguishing forest types. The two mid-IR red bands on TM (bands 5 and 7) are useful for vegetation and soil moisture studies, and discriminating between rock and mineral types. The thermal-IR band on TM (band 6) is designed to assist in thermal mapping, and for soil moisture and vegetation studies.

The Landsat images in this publication are color composite images created by assigning colors to bands. Typically, MSS Bands 4, 2, and 1 can be combined to make false-color composite images where band 4 represents red, band 2, green, and band 1, blue. This band combination makes vegetation appear as shades of red, brighter reds indicating more vigorously growing vegetation. Soils with no or sparse vegetation will range from white (sands) to greens or browns depending on moisture and organic matter content. Water bodies will appear blue. Deep, clear water will be dark blue to black in color, while sediment-laden or shallow waters will appear lighter in color. Urban areas will appear blue-gray in color. Clouds and snow will be bright white. They are usually distinguishable from each other by the shadows associated with

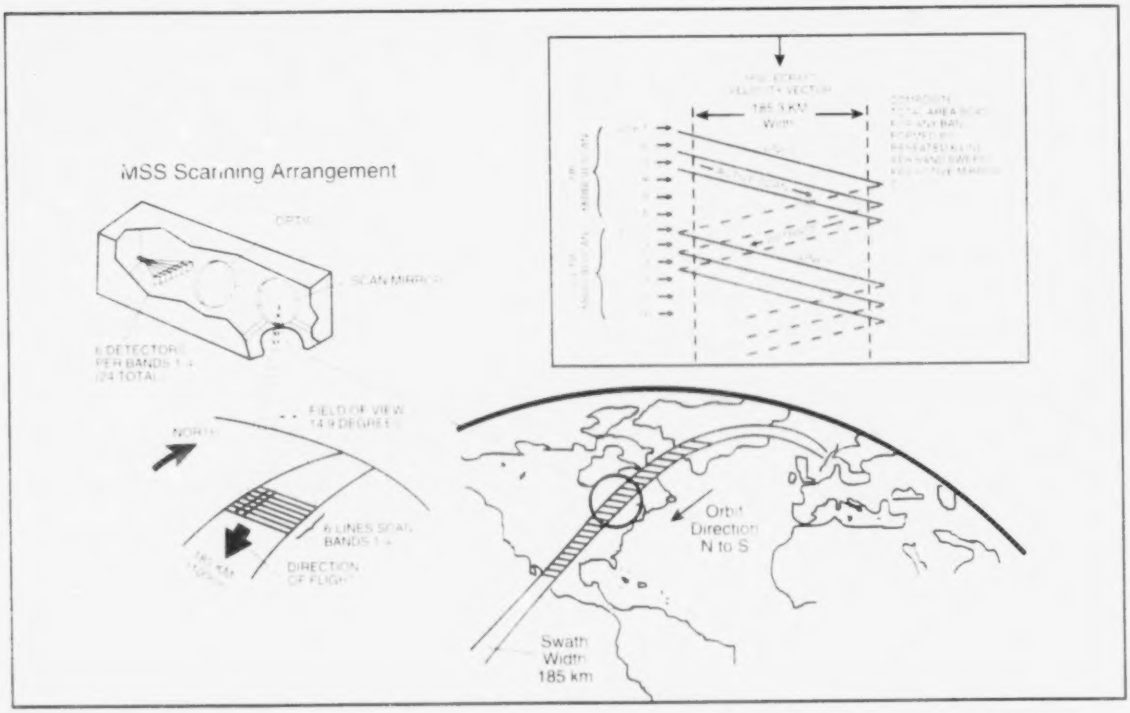


Figure 3. Scanning geometry of the multispectral scanner (from Landsat 4 Data Users Handbook, 1984, USGS).

the clouds. False-color composites can be created with TM data using bands 4, 3, and 2 in red, green, and blue, respectively. The images in this document include examples of both MSS and TM data.

Applications of Landsat Data

Landsat data have been used by government, commercial, industrial, civilian, and educational communities in the U.S. and worldwide. They are being used to support a wide range of applications in such areas as global change research, agriculture, forestry, geology, resources management, geography, mapping, water quality, and oceanography. The Landsat data in this booklet illustrate some of the dramatic changes that have taken place on the Earth in the past 20 years and demonstrate potential applications for monitoring the conditions of the Earth's land surface. The images provide examples of anthropogenic and natural changes on the Earth over periods of several months to more than 15 years. The changes include agricultural development, deforestation, natural disasters, urbanization, and the development and degradation of water resources. The inclination of the orbit has not been corrected in these images, which means each image is oriented about 10 degrees east of north. The locator map on the following pages provides a quick geographic reference to the images. These images represent a small proportion of the Landsat data archive at the EDC. The MSS archive has over 600,000 scenes with a data volume of 20 terabytes. The TM archive has over 300,000 scenes with a data volume of over 50 terabytes.

Table 2

Radiometric range of bands and resolution for the MSS sensor (from Landsat Data Users Handbook, 1979 and 1984, USGS)

Landsats 1-3	Landsats 4-5	Wavelength (micrometers)	Resolution (meters)
Band 4	Band 1	0.5 - 0.6	79/82*
Band 5	Band 2	0.6 - 0.7	79/82
Band 6	Band 3	0.7 - 0.8	79/82
Band 7	Band 4	0.8 - 1.1	79/82
Band 8**		10.4 - 12.6	237

* The nominal altitude was changed from 920 km for Landsats 1 to 3 to 705 km for Landsats 4 and 5 which resulted in a resolution of approximately 79 and 82 meters respectively.

** Landsat 3 only

Table 3

Radiometric range of bands and resolution for the TM sensor (from Landsat 4 Data Users Handbook, 1984, USGS)

Landsats 4-5	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	120
Band 7	2.08-2.35	30

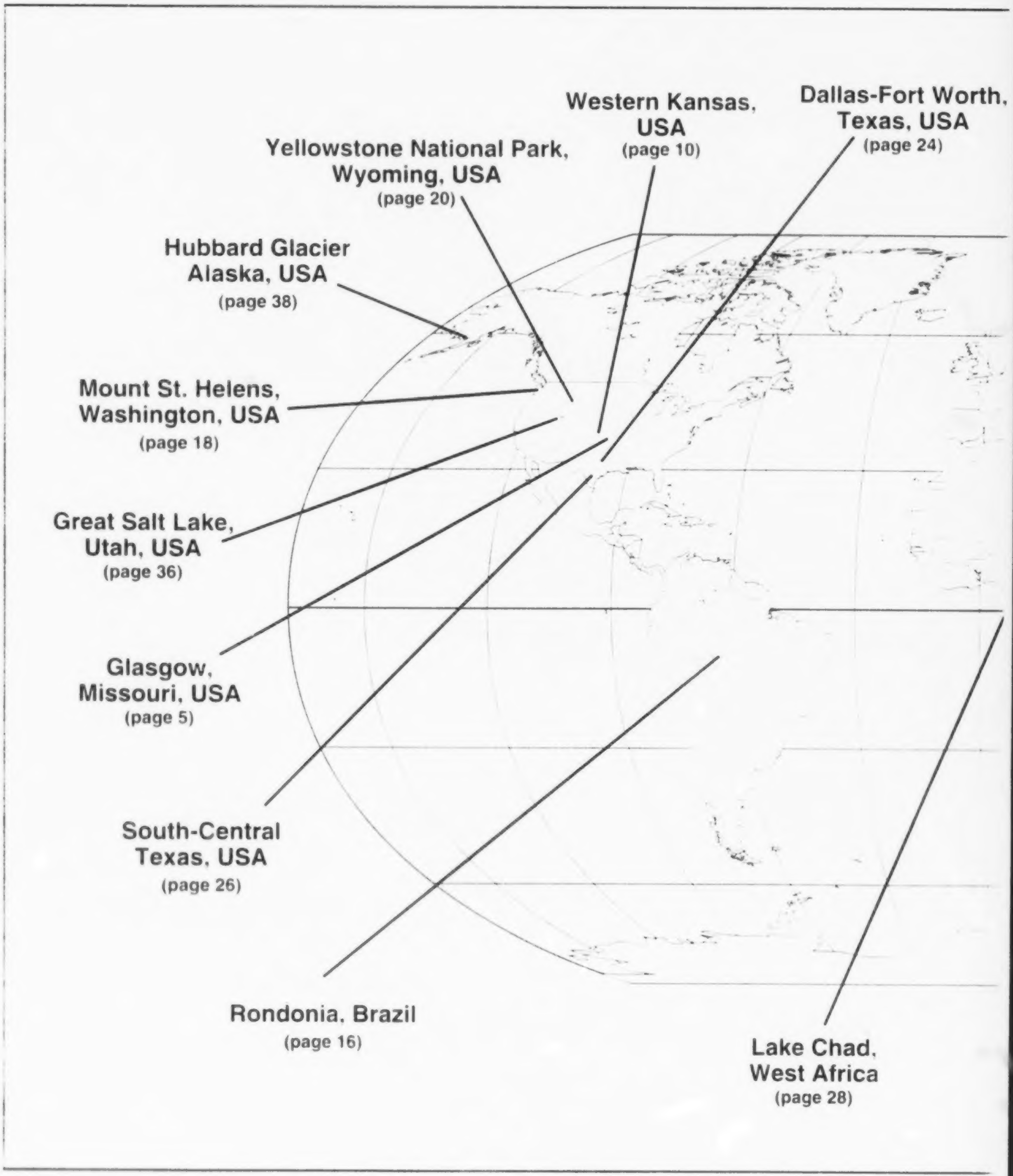
About the Cover

Upper Mississippi River Basin Flood of 1993

A series of heavy summer rains, following an unusually wet period from the summer and fall of 1992 through the spring of 1993, caused severe flooding along the Mississippi and Missouri rivers during the summer of 1993. The Landsat TM image on the left shows the Missouri River near Glasgow, Missouri (right side of the image). This image, acquired on September 24, 1992, prior to the floods, shows the extensive agricultural activities in the floodplain and a large oxbow lake (in the upper left of the image).

The TM image on the right was acquired on September 27, 1993, near the maximum flood peak. The flooding below Glasgow extends from bluff to bluff. The flooding upriver has inundated the agricultural fields and the oxbow lake. Terraces above the oxbow lake, predominately light brown and tan, were not flooded during this period.

Locator Map


Western Kansas, USA (page 10)
Dallas-Fort Worth, Texas, USA (page 24)
Yellowstone National Park, Wyoming, USA (page 20)
Hubbard Glacier Alaska, USA (page 38)
Mount St. Helens, Washington, USA (page 18)
Great Salt Lake, Utah, USA (page 36)
Glasgow, Missouri, USA (page 5)
South-Central Texas, USA (page 26)
Rondonia, Brazil (page 16)
Lake Chad, West Africa (page 28)

640

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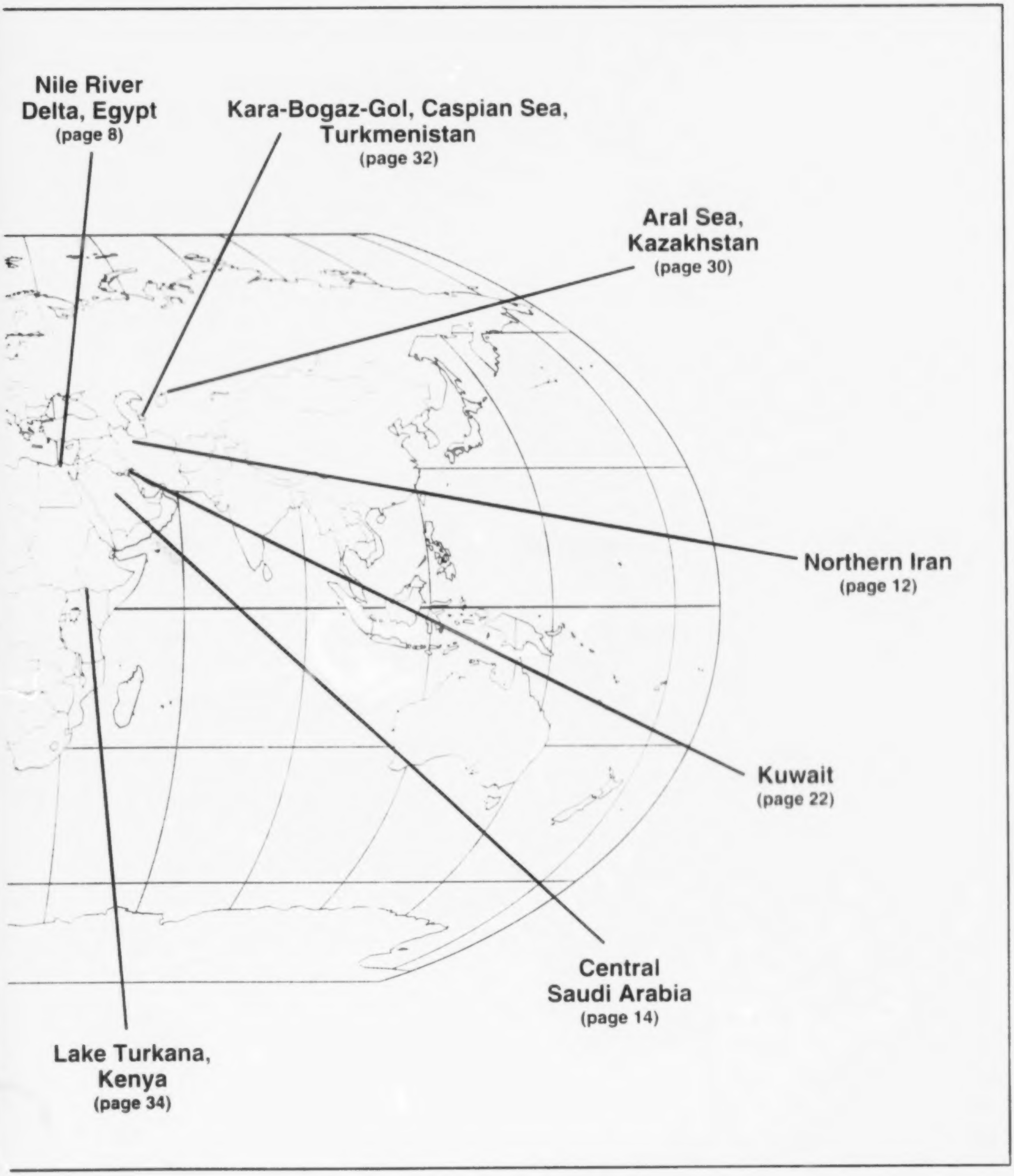
Nile River Delta, Egypt (page 8)
Kara-Bogaz-Gol, Caspian Sea, Turkmenistan (page 32)
Aral Sea, Kazakhstan (page 30)
Northern Iran (page 12)
Kuwait (page 22)
Central Saudi Arabia (page 14)
Lake Turkana, Kenya (page 34)

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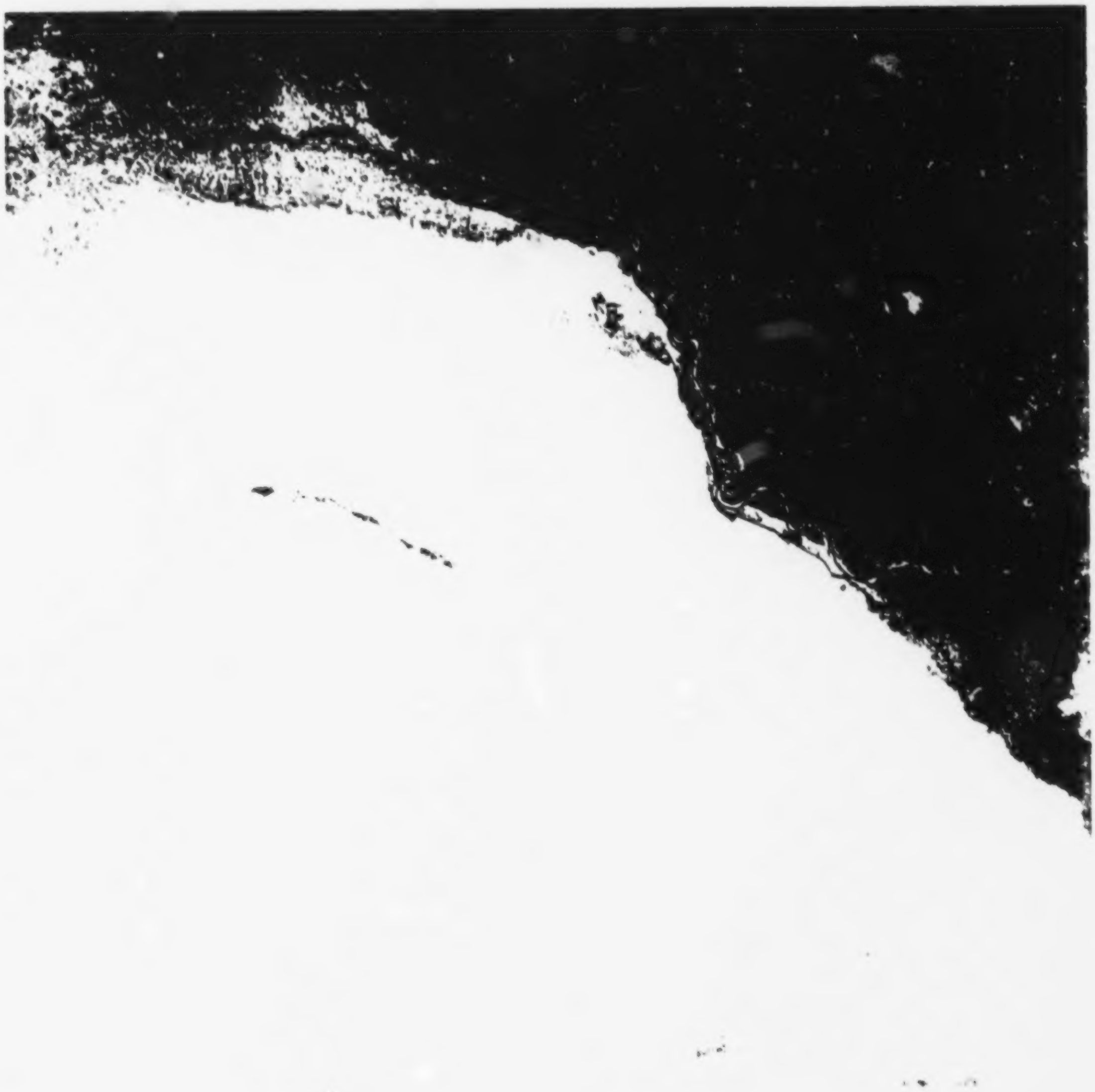
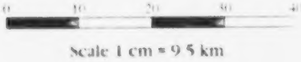
Agricultural Development
Urban Growth

Nile River Delta, Egypt





Scale 1 cm = 9.5 km

Landsat MSS
May 10, 1973

Images from May 10, 1973, and July 18, 1987, show the dramatic urban growth within the Nile River delta and the expansion of agriculture into adjoining desert areas. Cairo, Egypt, shown as the large blue-gray expanse in the right-central portion of each image, increased in population from 1.5 million in 1947 to 6 million in 1986. It now has a population density of more than 26,000 people per square

642

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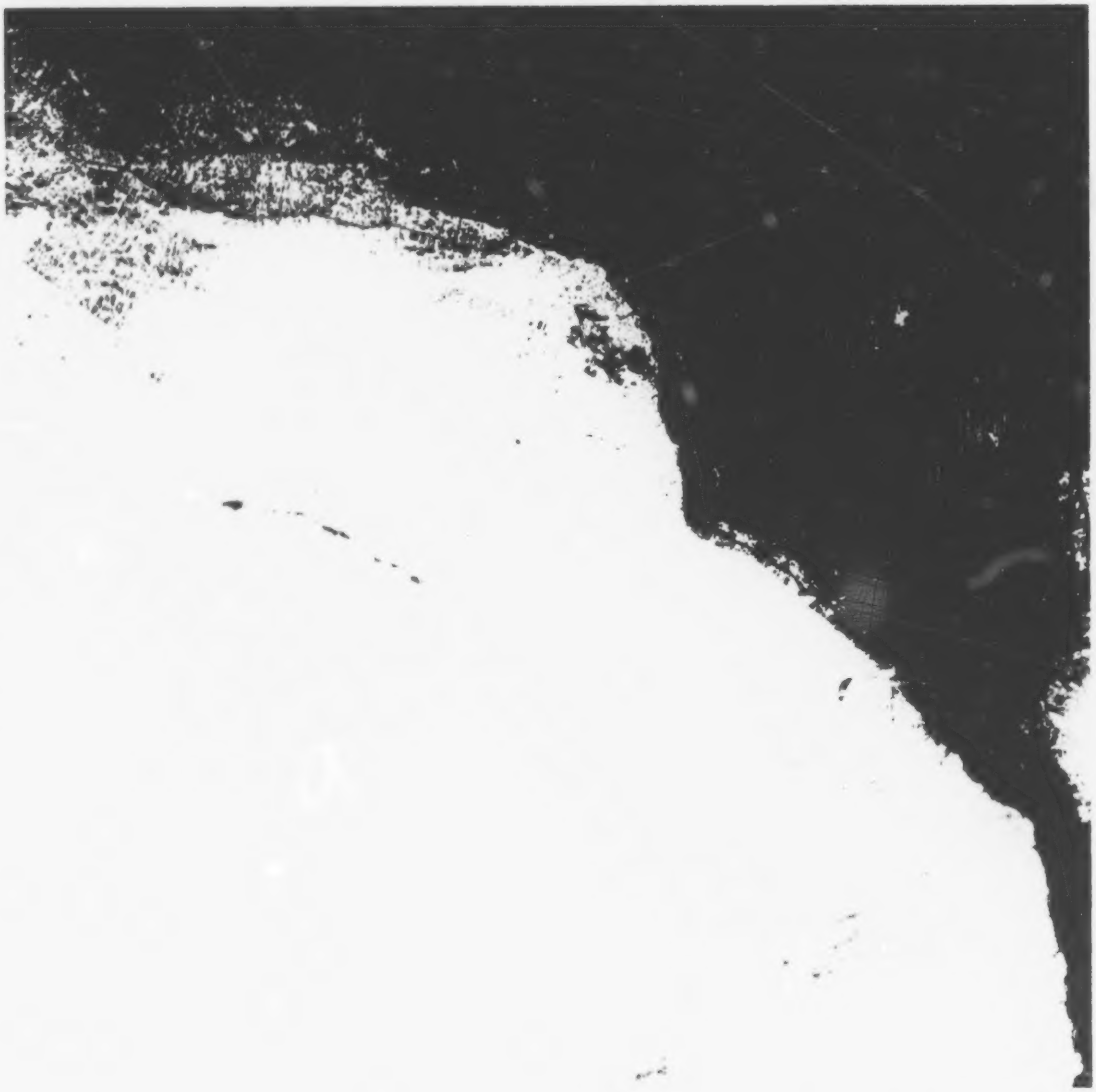
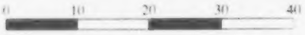


kilometer or more than 11 million people. Urban expansion is also noticeable in the other parts of the delta by the increase in the blue-gray areas in the 1987 image. The area of vegetation just outside the delta in the upper-left area of each image is new agricultural development. Some of the crops in this area are irrigated using center-pivot irrigation. Areas under this type of irrigation appear as red circles.



Scale 1 cm = 9.5 km.

Landsat MSS
July 18, 1987

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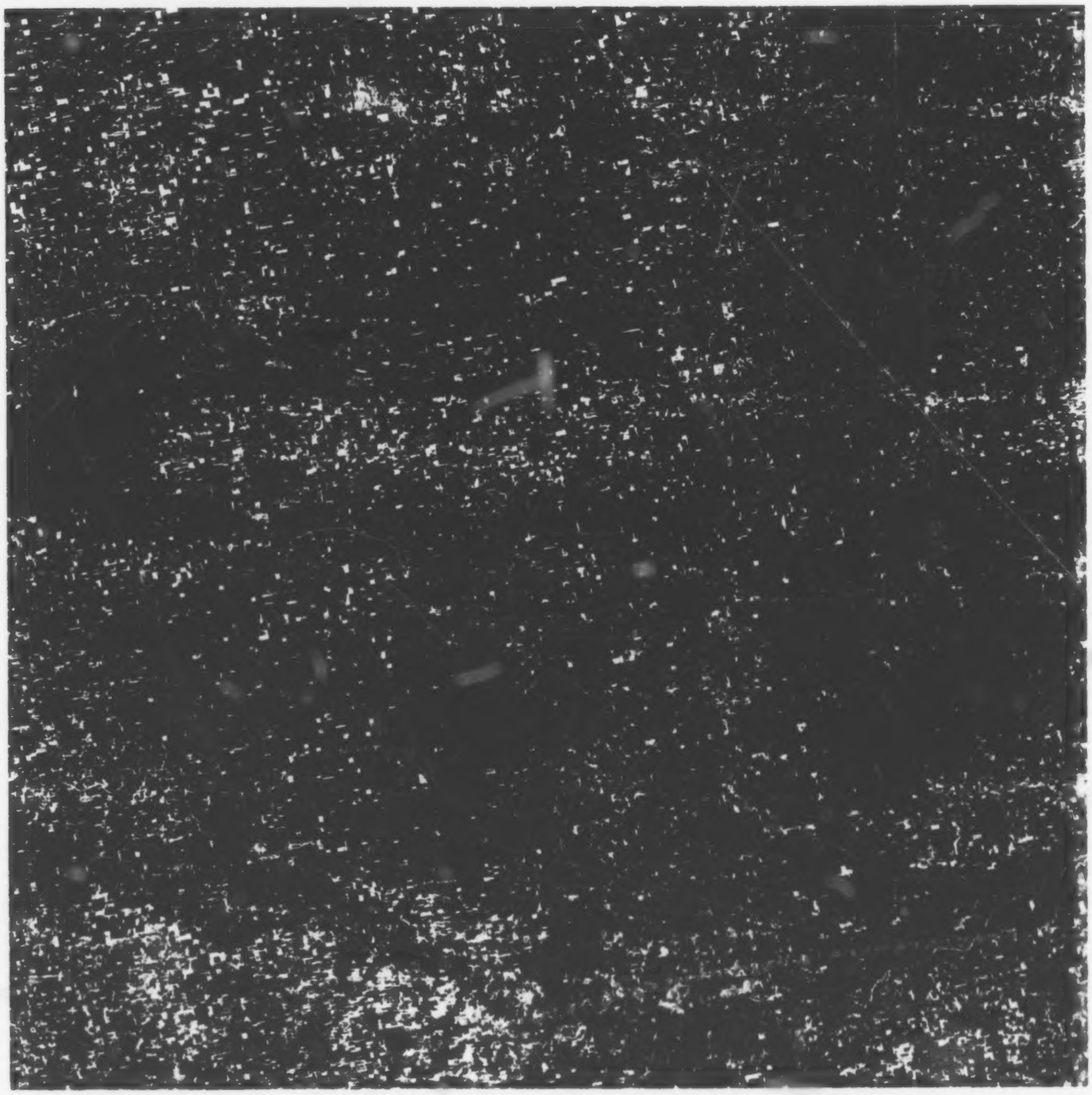
Western Kansas, USA



Scale 1 cm = 9.5 km

Landsat MSS
August 16, 1972

Much of the natural shortgrass prairie of western Kansas is now irrigated cropland. The number of center-pivot irrigation systems in Finney County and adjacent areas of western Kansas has increased dramatically since the early 1970's. Irrigation is possible because of the water available from the Ogallala aquifer, which underlies an area from Nebraska and Wyoming south to the Texas Panhandle. These two August

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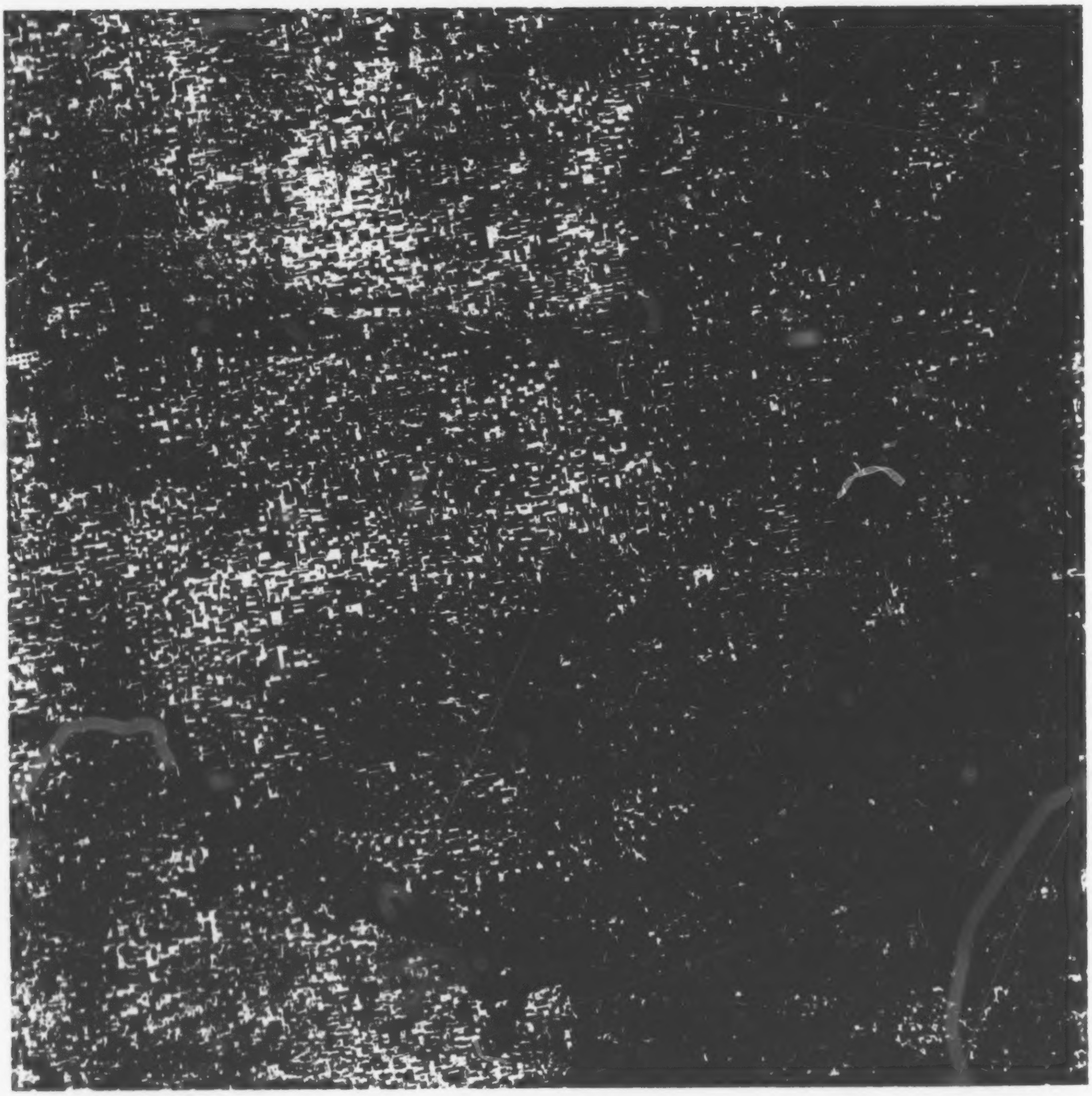

images show center-pivot irrigated crops as red circles. The predominant crop in this area of Kansas is corn. Light-colored cultivated fields in the images are fallow or recently harvested wheat fields. Images such as these play a major role in providing an inventory of irrigated crop acreage, a key component of modeling aquifer response to changes in water use.

0 10 20 30 40

Scale 1 cm = 9.5 km

Landsat MSS
August 15, 1988

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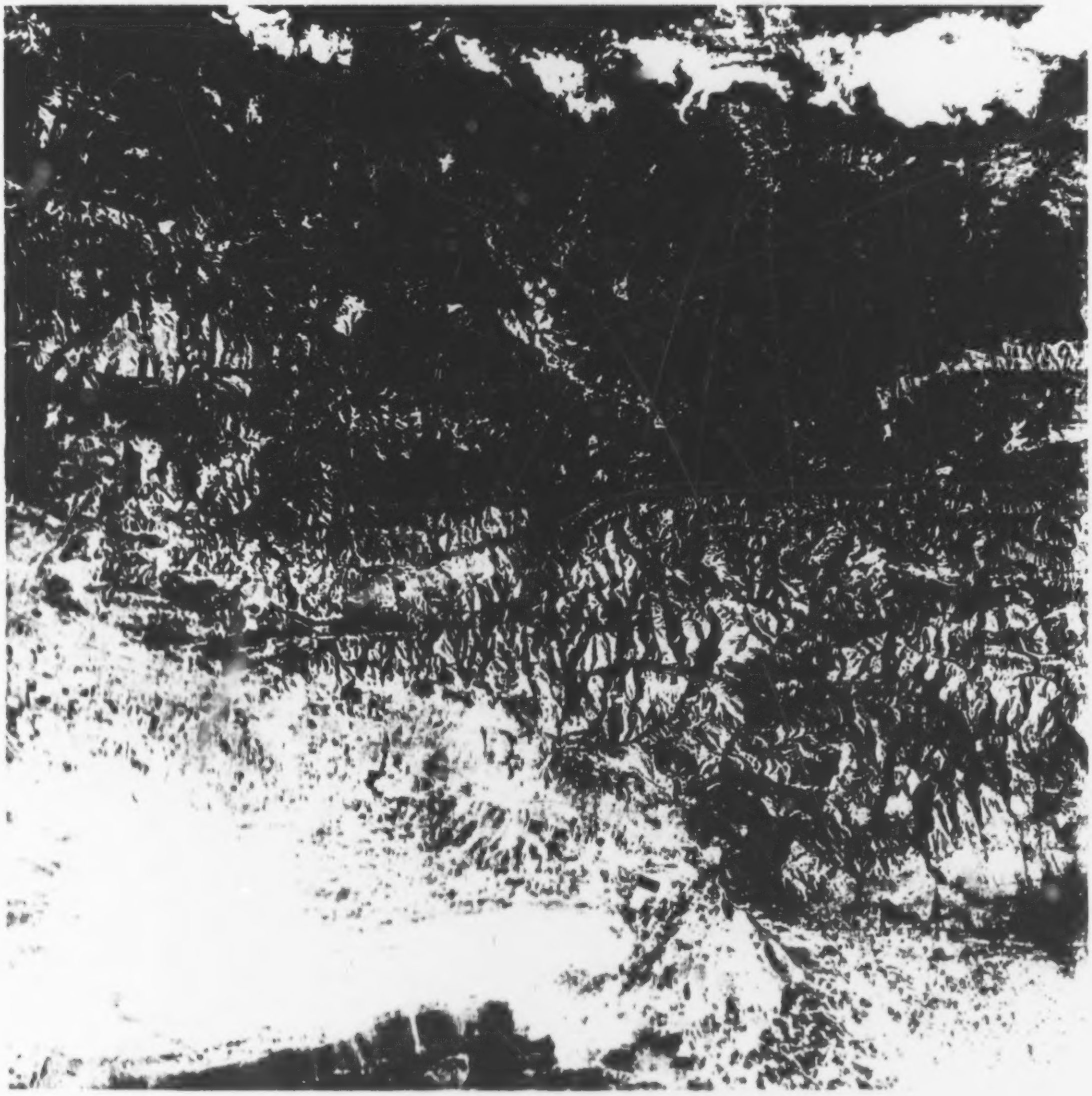
Northern Iran



0 10 20 30

Scale 1 cm = 7.6 km

Landsat MSS
July 14, 1977

Irrigated agriculture, shown by the red tones of the field patterns, has increased in the valley (central part of each image) south of the Elburz Mountains in northern Iran, as depicted by these July 14, 1977, and September 16, 1987, images. These mountains run parallel to the Caspian Sea and act as a barrier to rain clouds moving southward. As the rain clouds rise in altitude to cross the mountains, they drop their

646

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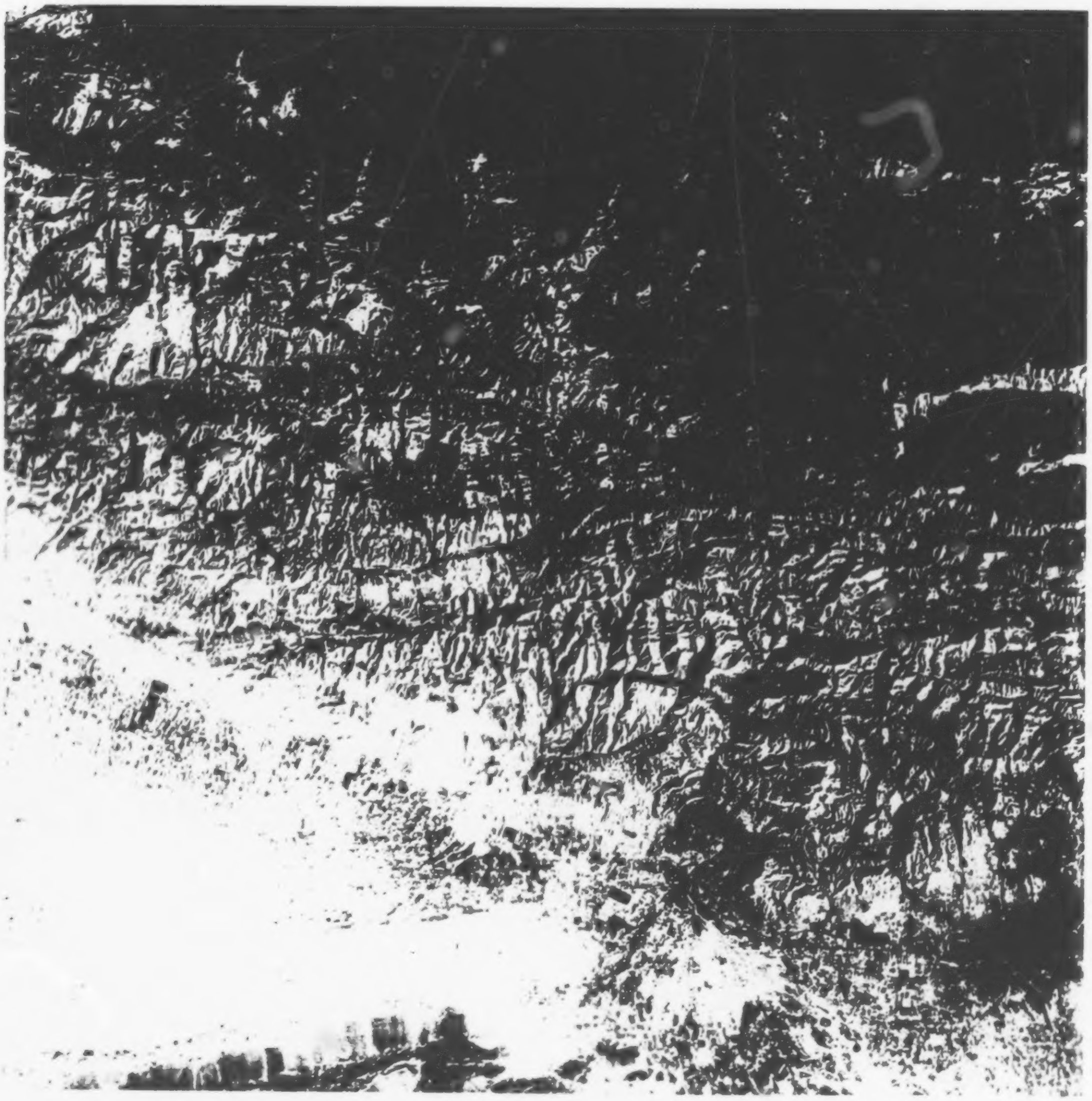

moisture. This abundant rainfall supports a heavy rainforest on the northern slopes of the Elburz Mountains, the rainforest appears as contiguous dark red areas in the upper-right portion of the images. The valley to the south of the mountains receives little or no precipitation because of the rain-shadow effect of the mountains. Agriculture in the valley depends on rainfall captured in the mountains and channeled to the valley floor and on nearby rivers and wells.

0 10 20 30

Scale 1 cm = 7.6 km

Landsat MSS
September 16, 1987

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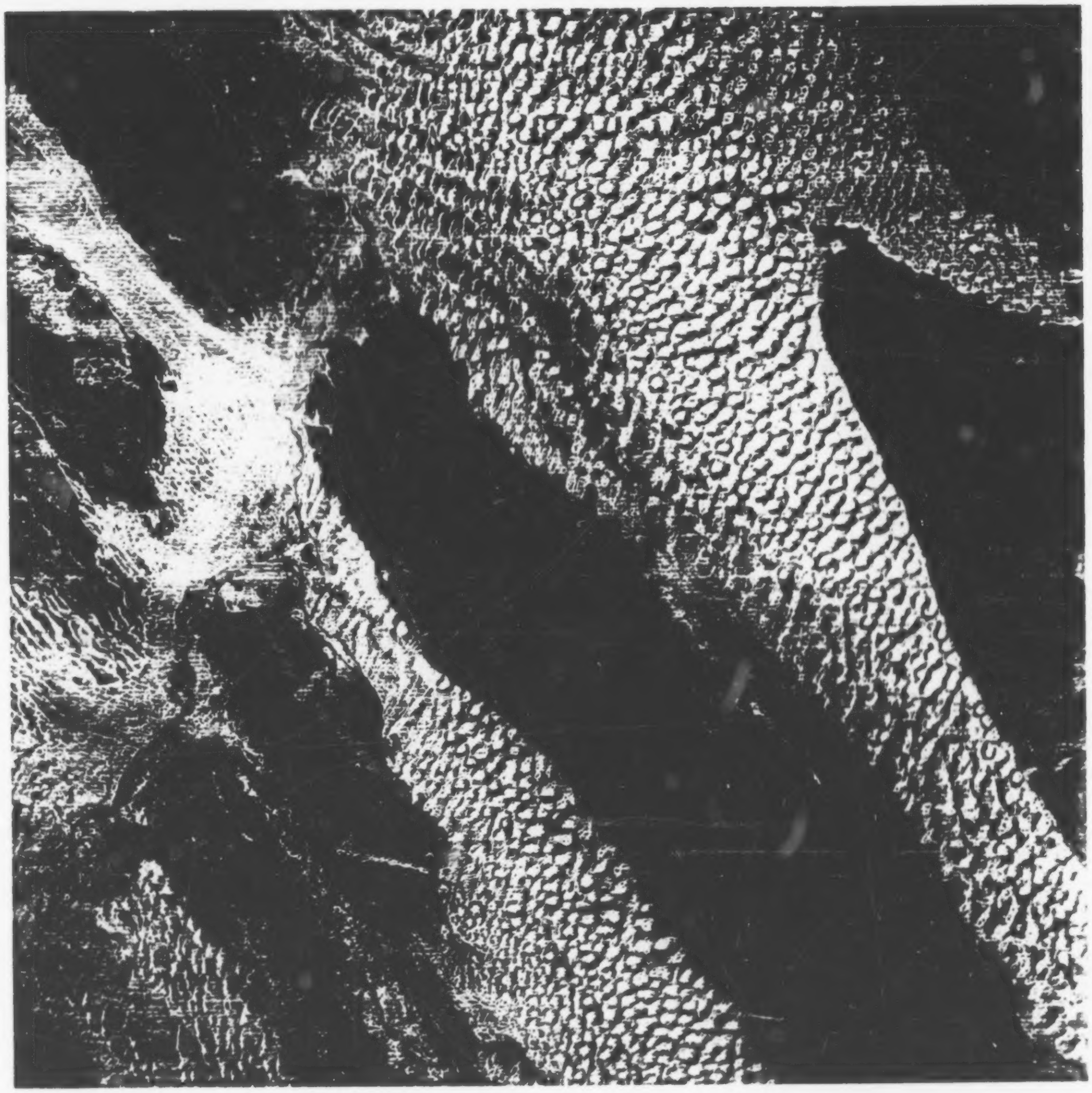
Central Saudi Arabia



Scale 1 cm = 6.9 km

Landsat MSS
December 25, 1972

The development of center-pivot irrigation agriculture in Saudi Arabia is shown in these images acquired on December 25, 1972, and February 15, 1986. The 1986 image shows the dramatic impact of center-pivot irrigation systems. Areas under this type of irrigation appear as red circles. Water from Saudi Arabia's aquifers is being used to grow crops such as wheat. The new irrigation systems extend beyond the image

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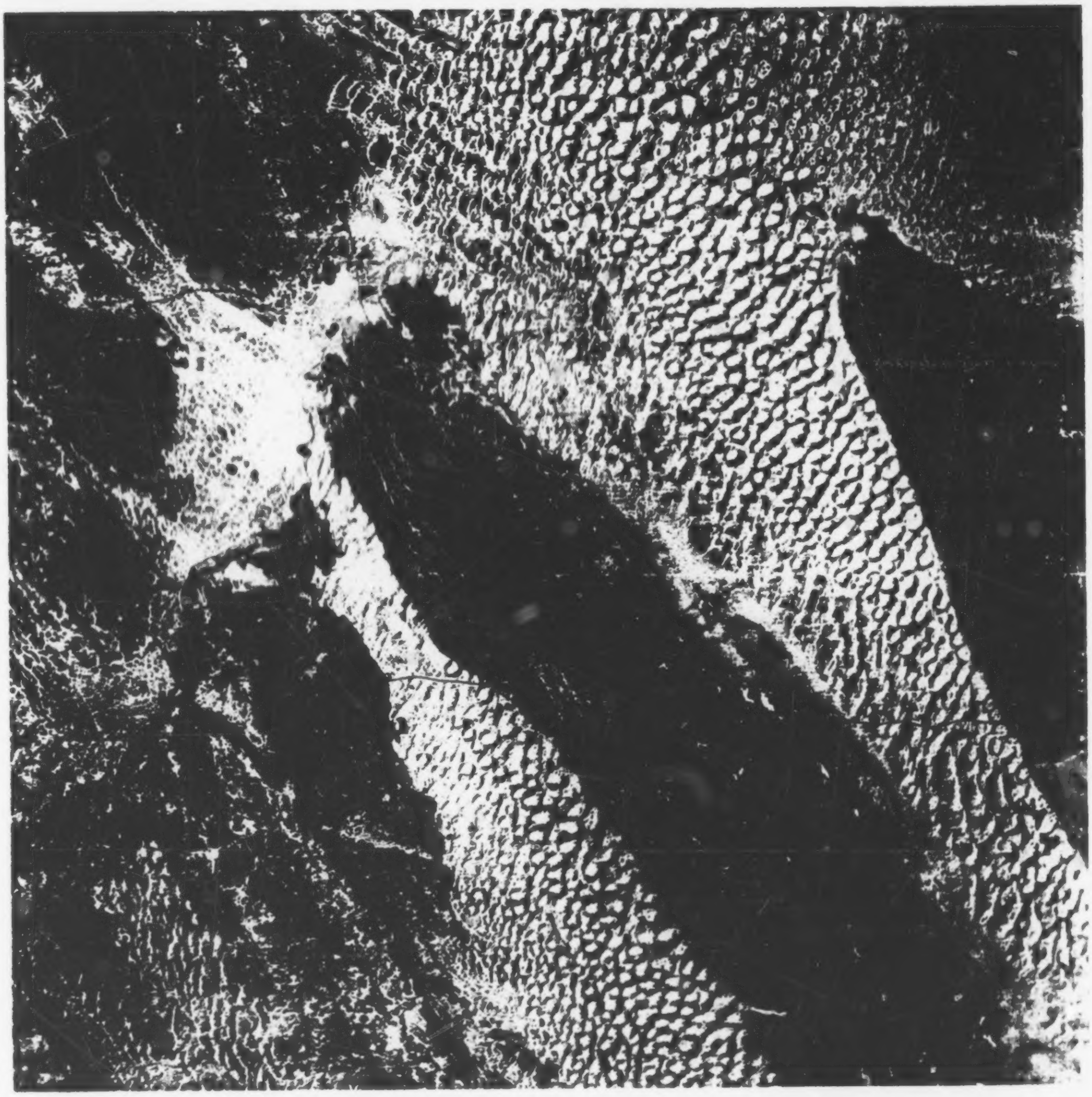

areas throughout the Buraydah-Riyadh region of Saudi Arabia. This irrigation development resulted from the investment of part of Saudi Arabia's oil revenues in an effort to modernize agricultural practices. The cities of Buraydah and Unayzah can be seen at the western edge of each image and a new highway can be seen running across the lower part of the 1986 image to Unayzah.

0 10 20 30

Scale 1 cm = 6.9 km

Landsat MSS
February 15, 1986

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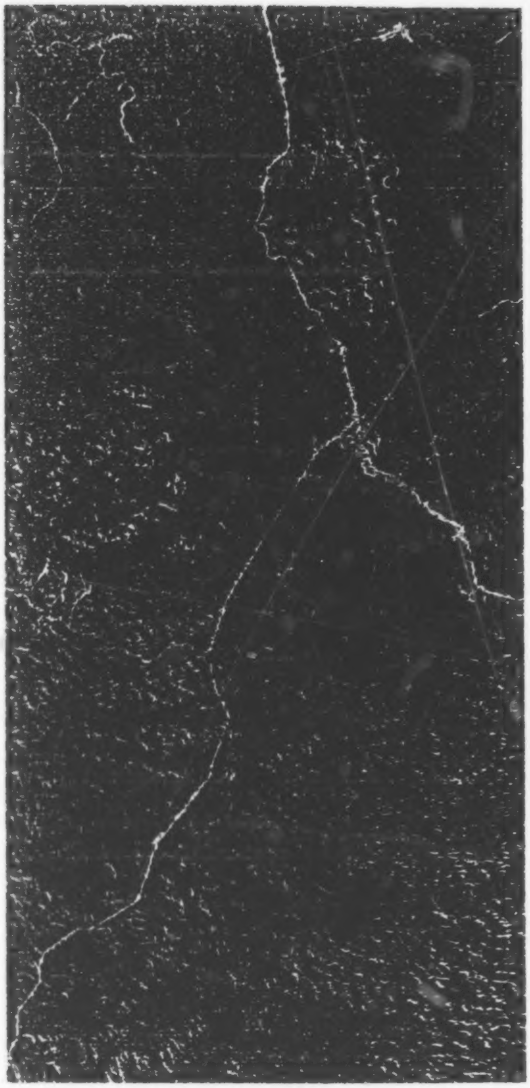
Rondonia, Brazil

These images show a portion of the state of Rondonia, Brazil, in which deforestation of the tropical forests has taken place. Approximately 30 percent or 3,562,800 km^2 of the world's tropical forests are in Brazil. The estimated average deforestation rate from 1978 to 1988 was 15,000 km^2 per year. Systematic cutting of the forest vegetation starts along roads and then fans out to create the "feather" or "fishbone" pattern shown in the August 1 1986, and June 22, 1992 images. The deforested land and urban areas appear as light blue; healthy vegetation appears red. Both MSS and TM data are used to demonstrate how this activity can be monitored.

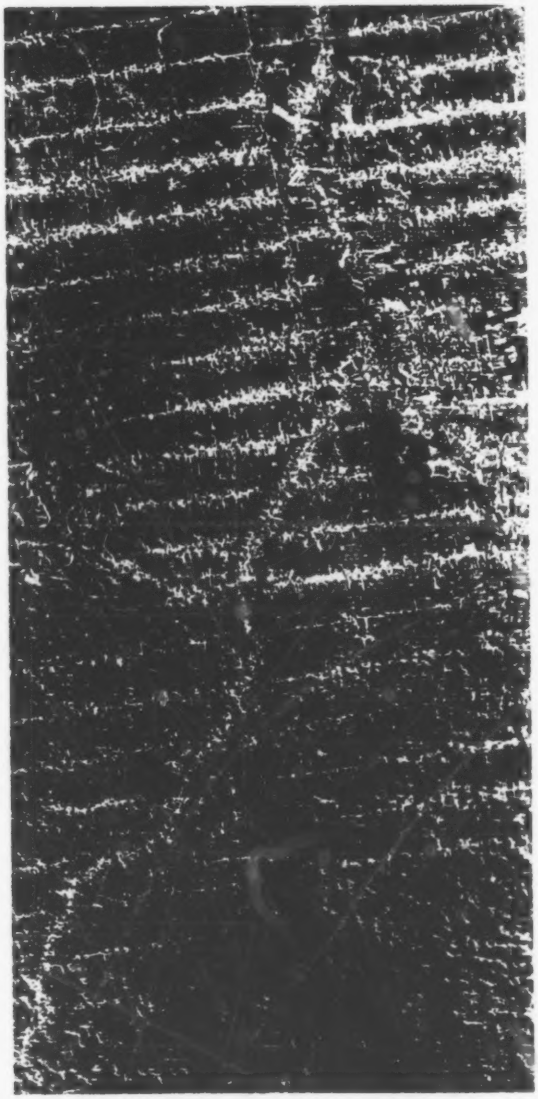
0 10 20 30 40

Scale 1 cm = 9 km

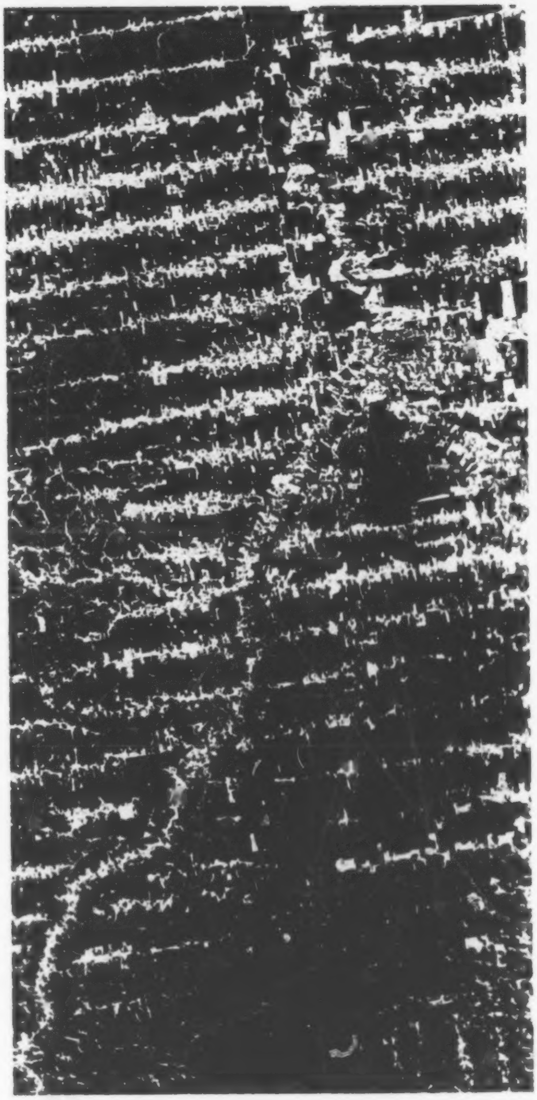


Landsat MSS
June 19, 1975

650



Landsat MSS
August 1, 1986



Landsat TM
June 22, 1992

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Forest Change
Natural Disasters

Mount St. Helens, Washington, USA

Three images document the changes in the vicinity of Mount St. Helens during the last 15 years. The September 15, 1973, image shows Mount St. Helens and adjacent forest land before the eruption on May 18, 1980. The May 22, 1983, image shows the extent of volcanic debris caused by the explosive eruption, with the collapsed north edge of the crater clearly evident. The area north of the crater is the most devastated, with mudslides, volcanic ash, and mud-laden rivers shown as grayish-blue areas. Spirit, Coldwater, and South Fork Castle Creek Lakes north of the volcano can be seen in the 1973 image, but are partially obscured in the May 22, 1983, image by the debris and ash flows. Swift Reservoir and Yale Lake, south of the mountain, received silt- and ash-laden runoff from the damaged areas. The volcano ejected an estimated 400 million tons of ash into the atmosphere and devastated an area of 600 km^2.

The August 31, 1988, image shows some vegetation regrowth, light red and pink, in the devastated area. The patchwork block patterns in the forested land east of Mount St. Helens are areas where timber has been removed. This image shows an increase in the timber harvested from land in this region when compared with the September 15, 1973, image. The city of Portland, Oregon, is visible in the bottom of each image as are the Columbia and Willamette Rivers.

Scale 1 cm = 9.5 km.

Landsat MSS
September 15, 1973

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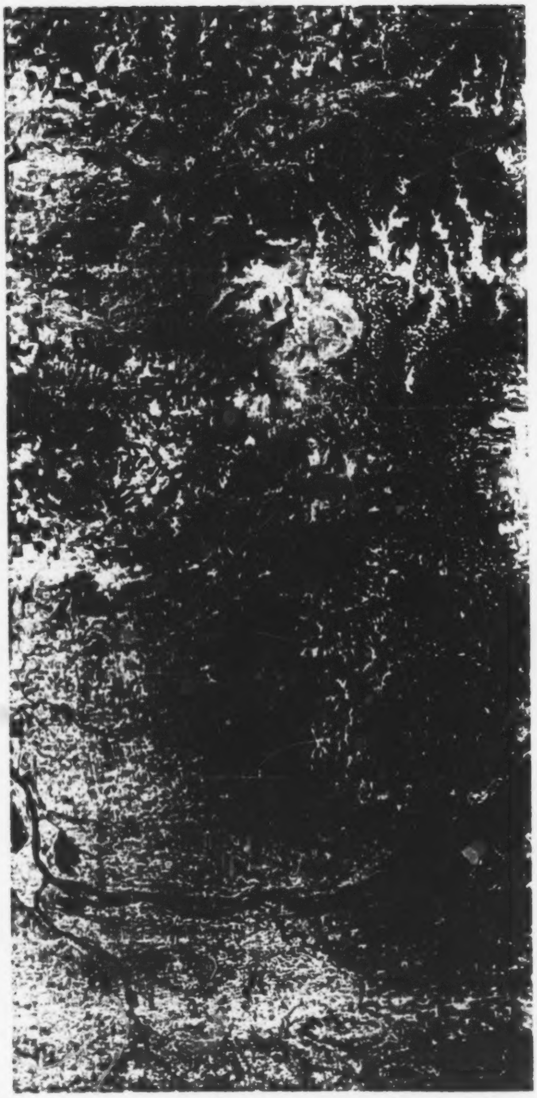
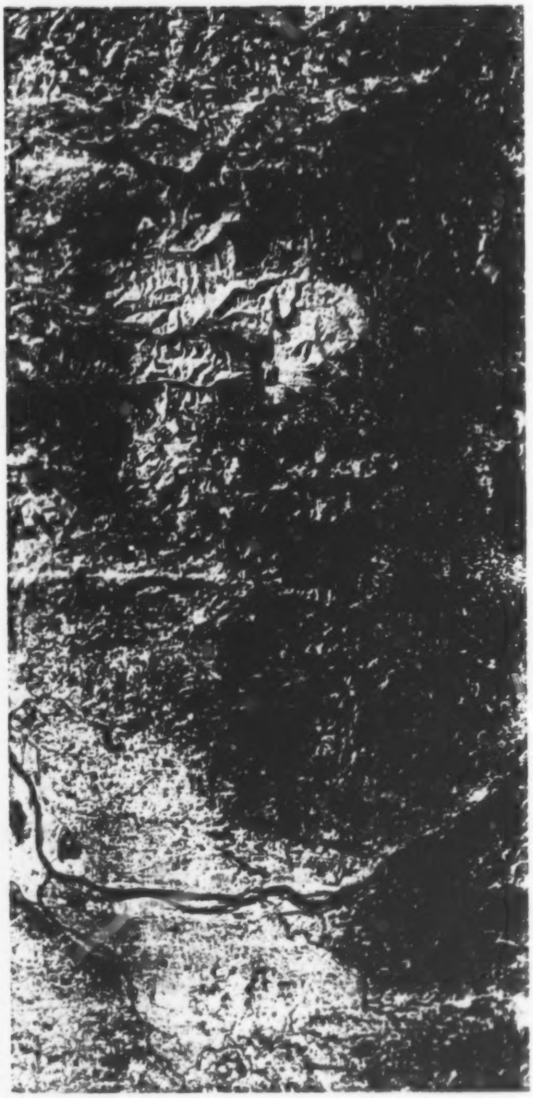


Landsat MSS
May 22, 1983



Landsat MSS
August 31, 1988

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Yellowstone National Park, Wyoming, USA

Scale 1 cm = 9.5 km

Landsat TM
July 22, 1988

These images from July 22, 1988, and October 2, 1988, document the dramatic forest fires that occurred in and adjacent to Yellowstone National Park. These images were created using bands 7, 4, and 3 to make the burned areas easier to identify. This band combination depicts water bodies as dark blue, healthy vegetation in shades of green (conifer forest in dark green and grassland in light green tones), and burned vegetation in shades of red. Yellowstone Lake appears as the large dark blue feature in the center portion of the image. The lake on the left edge of the image is Hebgen Lake.

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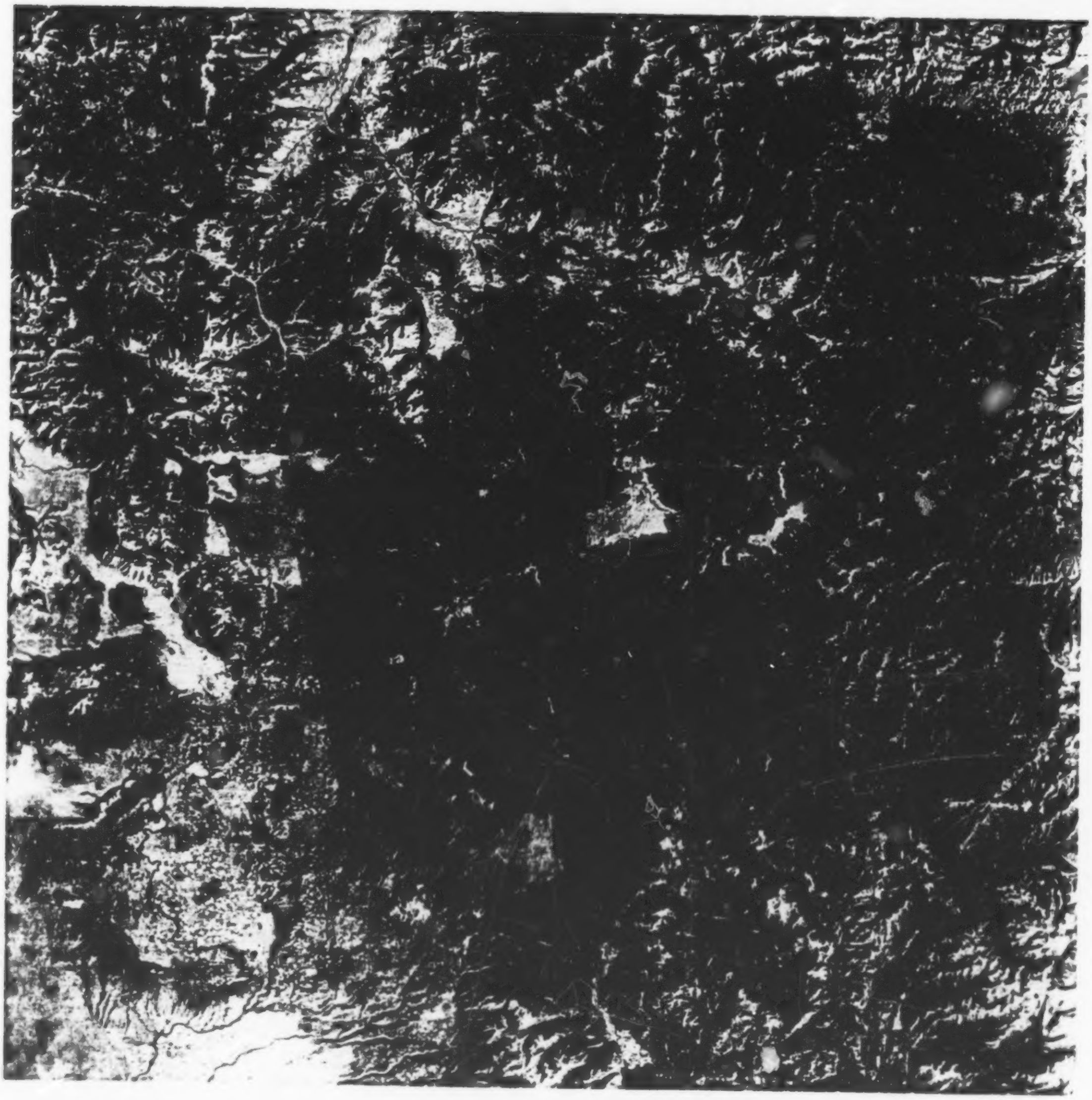

Scale 1 cm = 9.5 km

The first fires of the fire season are documented on the July image. The Clover-Mist fire clearly appears in the right-center portion of the image. Smoke can be seen rising from the burned area.

The extent of the fires can be assessed from the October image. In this image all the fires have been extinguished and the burned areas are easily identified by the purple tones. Eight major fires swept through nearly half of the park's 2.2 million acres.

Landsat TM
October 2, 1988

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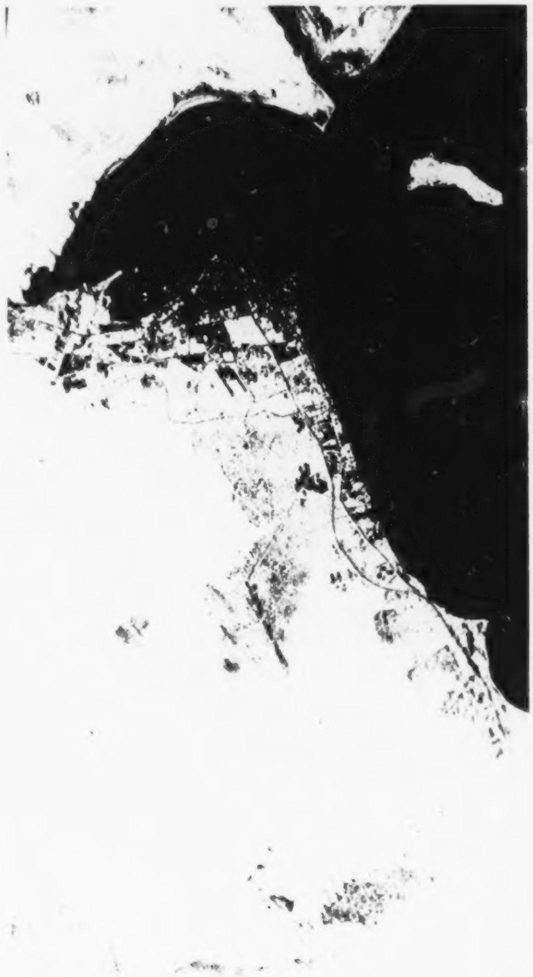
Kuwait

These images illustrate the extent of the oil fires in Kuwait ignited during the Persian Gulf war. The August 31, 1990, image shows the capital city of Kuwait in the upper-center part of the image. In the February 23, 1991, image the Kuwaiti coastline below the city of Kuwait is obscured by smoke plumes from burning oil wells. The November 14, 1991, image was acquired after the fires had been extinguished. The results of the oil fires are evident by the black oil and soot deposits on the land surface, particularly below the city of Kuwait.

Scale 1 cm = 9.5 km



Landsat TM
August 31, 1990

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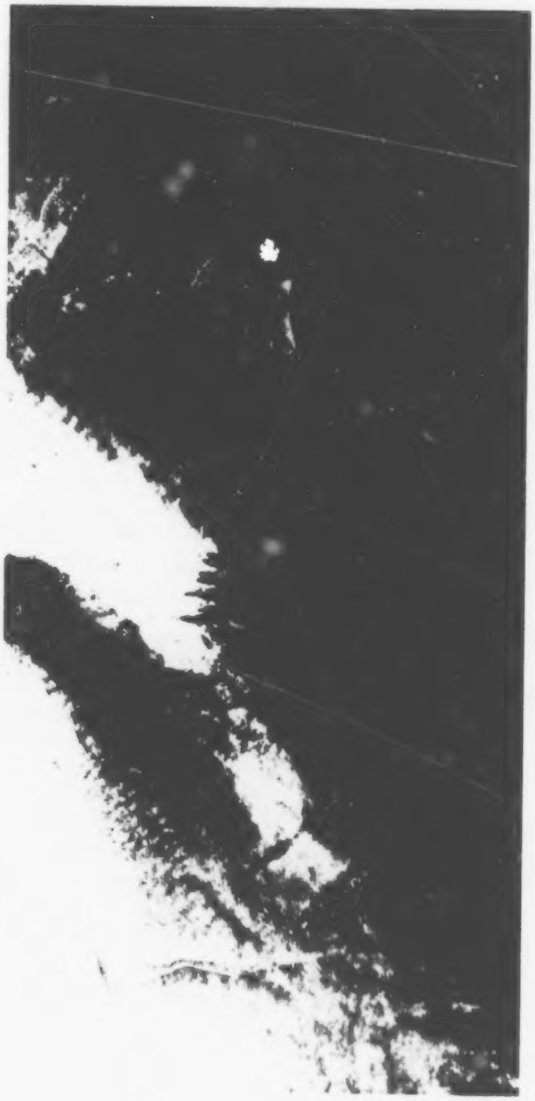
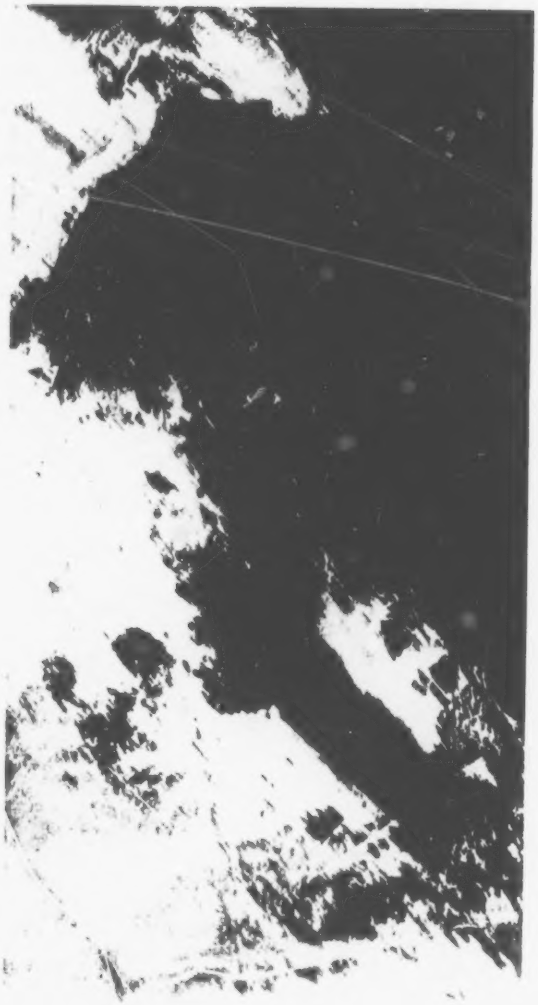


Landsat TM
February 23, 1991



Landsat TM
November 14, 1991

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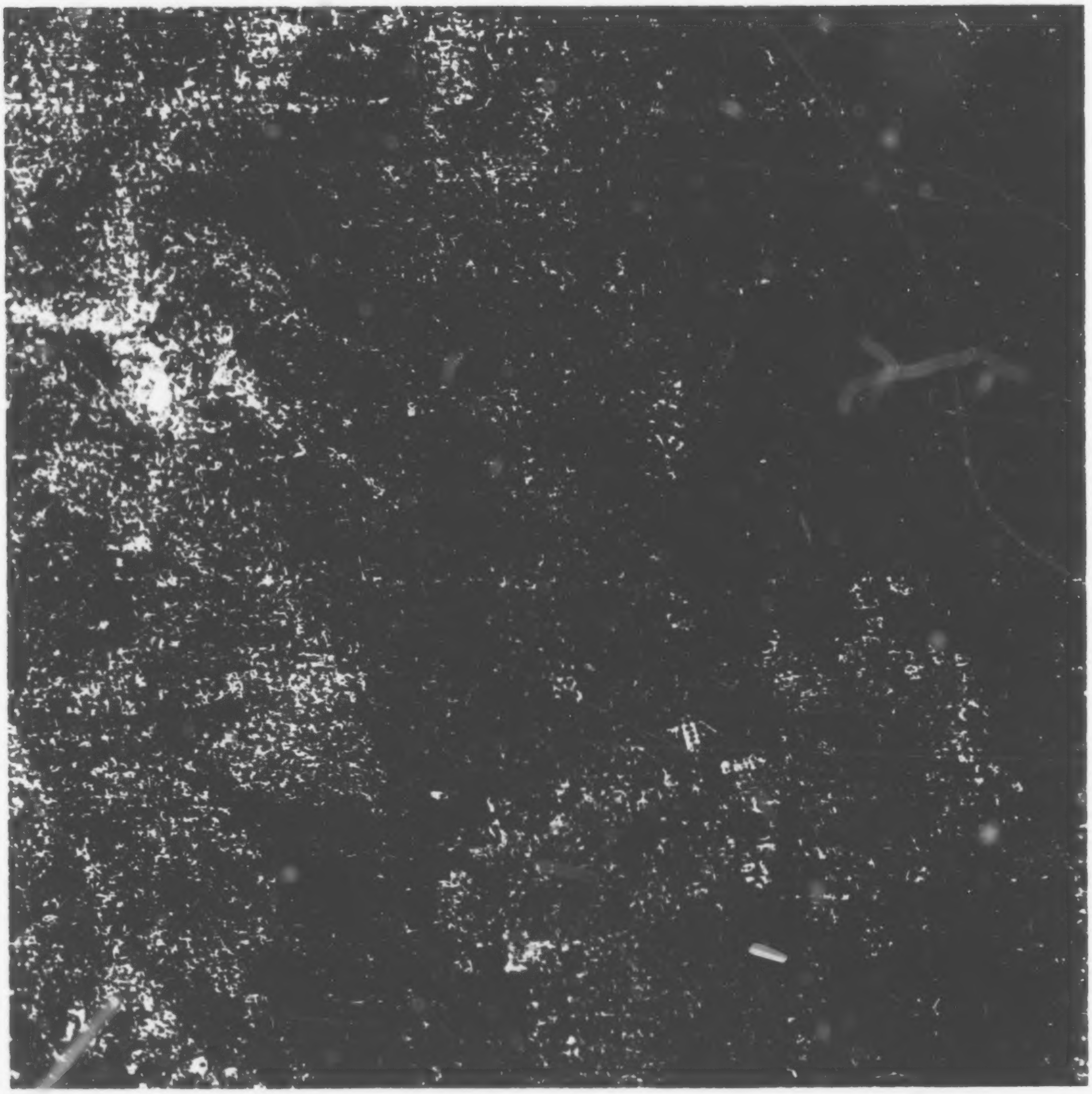
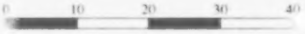
Dallas-Fort Worth, Texas, USA





Scale 1 cm = 9.5 km

Dallas-Fort Worth, Texas, has grown significantly in the last 20 years. These images acquired on March 12, 1974, and on March 22, 1989, show the expansion of urban areas into the surrounding countryside. The population of this metropolitan area grew from 2,378,000 in 1970 to 3,776,000 by 1988. The

Landsat MSS
March 12, 1974

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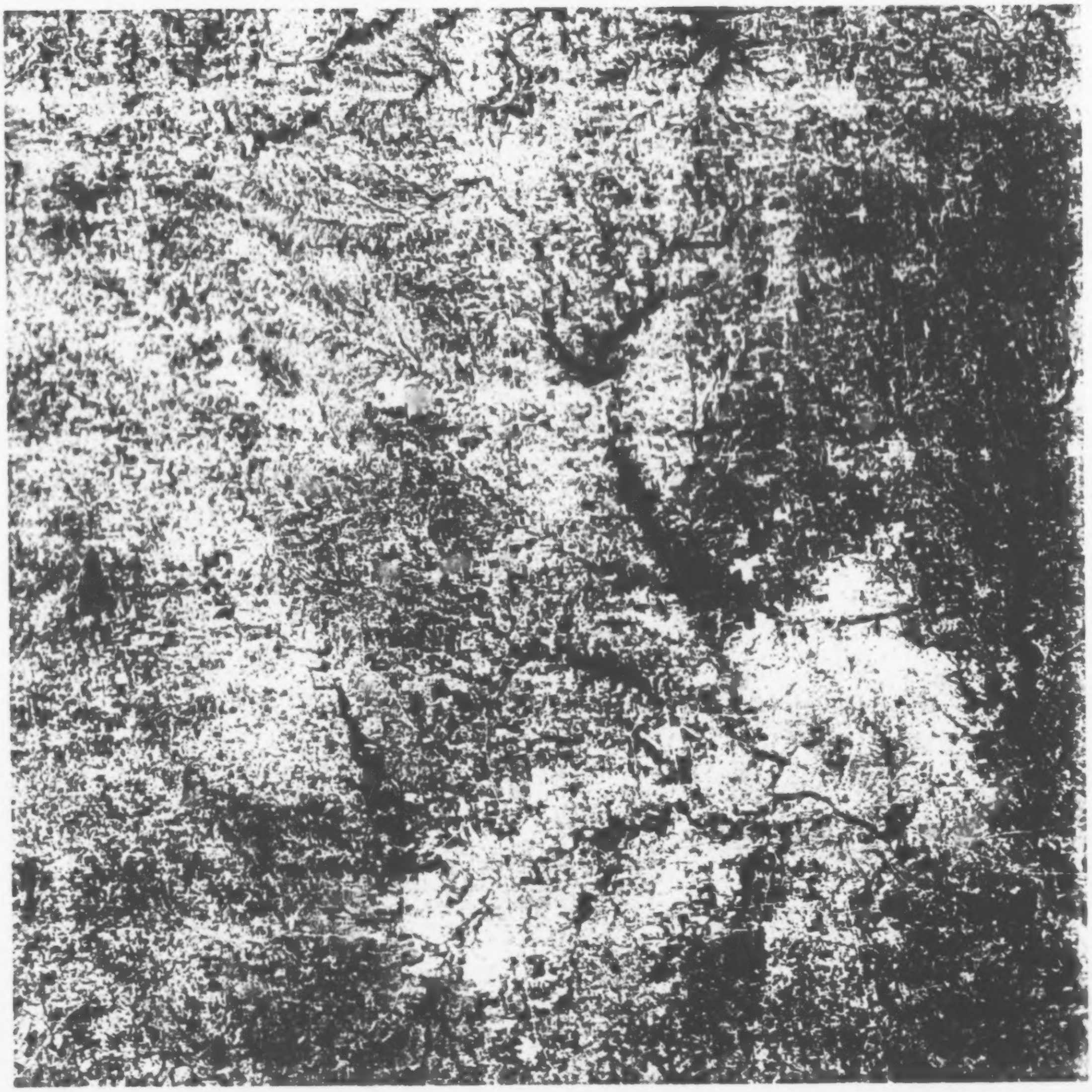

Ray Roberts Reservoir, northwest of Dallas, and Joe Pool Lake, southwest of Dallas, have been constructed since 1974. Also, the recently constructed Dallas-Fort Worth International Airport can be seen north of the Dallas-Fort Worth metropolitan area.

0 10 20 30 40

Scale 1 cm = 9.5 km

Landsat MSS
March 22, 1989

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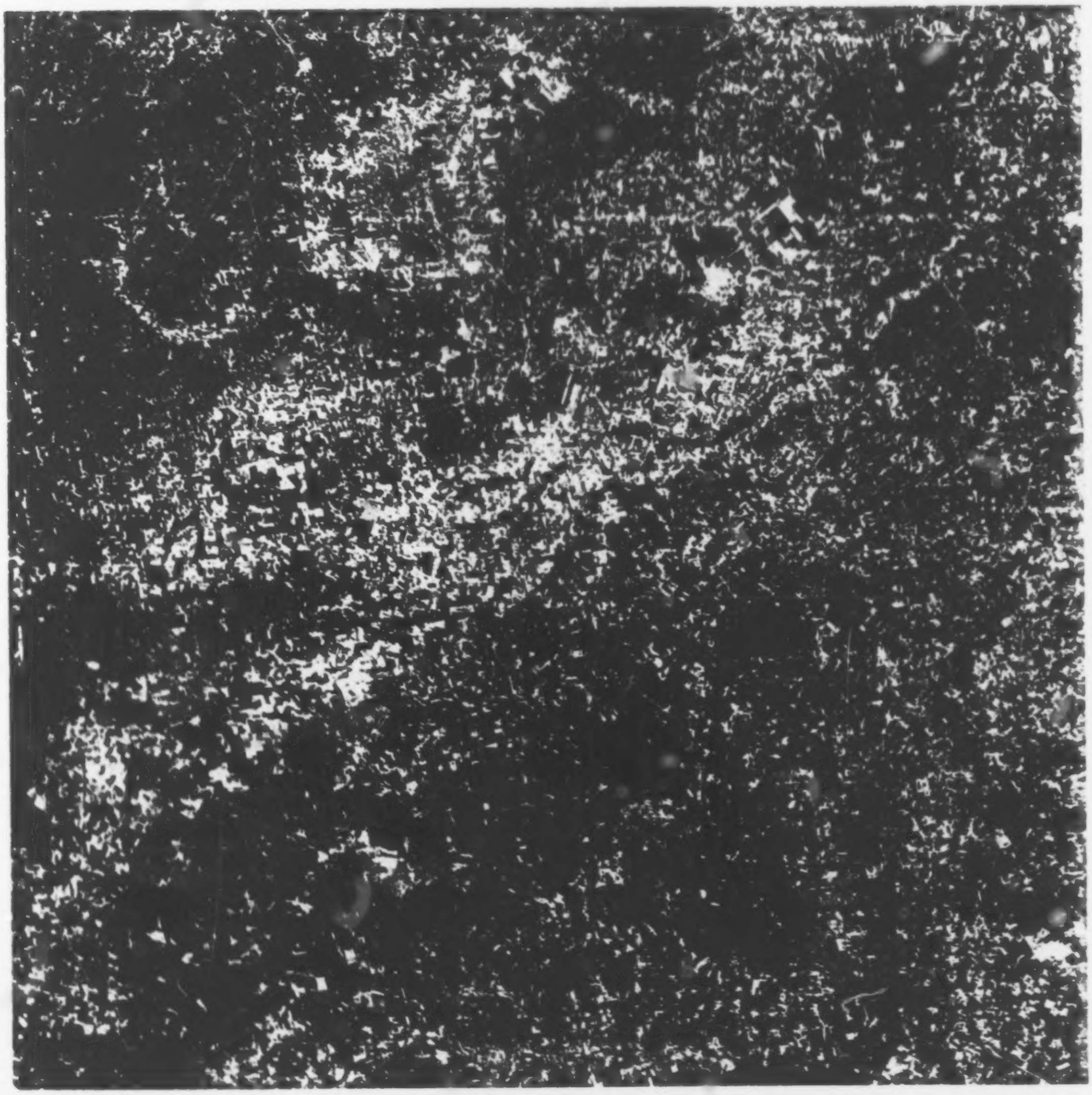
Urban Growth
Water Resources

South-Central Texas, USA



0 10 20 30 40

Scale 1 cm = 9.5 km

Images acquired over south-central Texas show the development of a new reservoir on the Frio River between February 4, 1974, and March 19, 1988. The resulting reservoir is Choke Canyon Reservoir near the town of Beeville, Texas.

Landsat MSS
February 4, 1974

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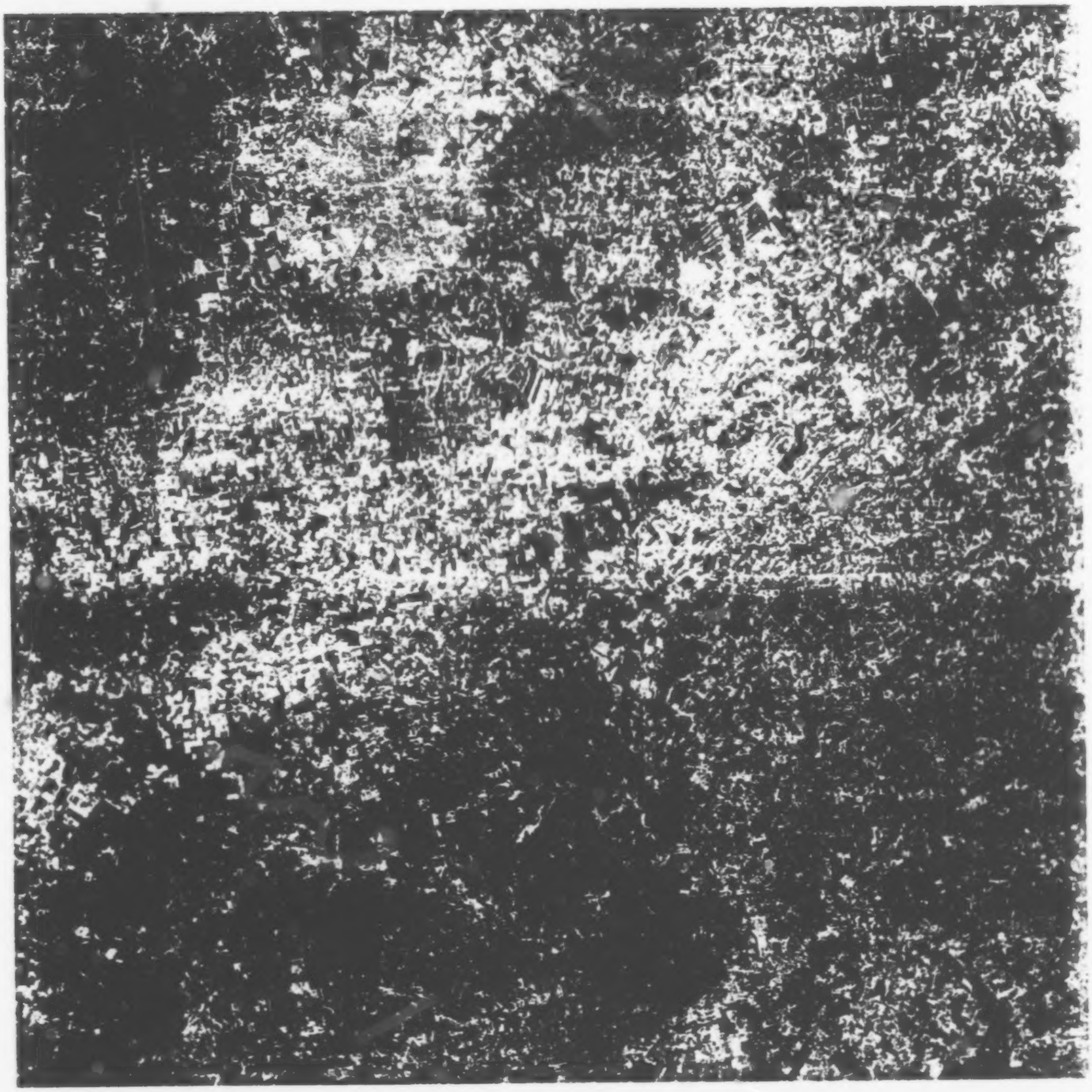 San Antonio, Texas, is shown in the upper-left-hand corner of each image. Note the dramatic growth of the city from approximately 654,000 in 1970 to more than 936,000 in 1990.

Scale 1 cm = 9.5 km

Landsat MSS
March 19, 1988

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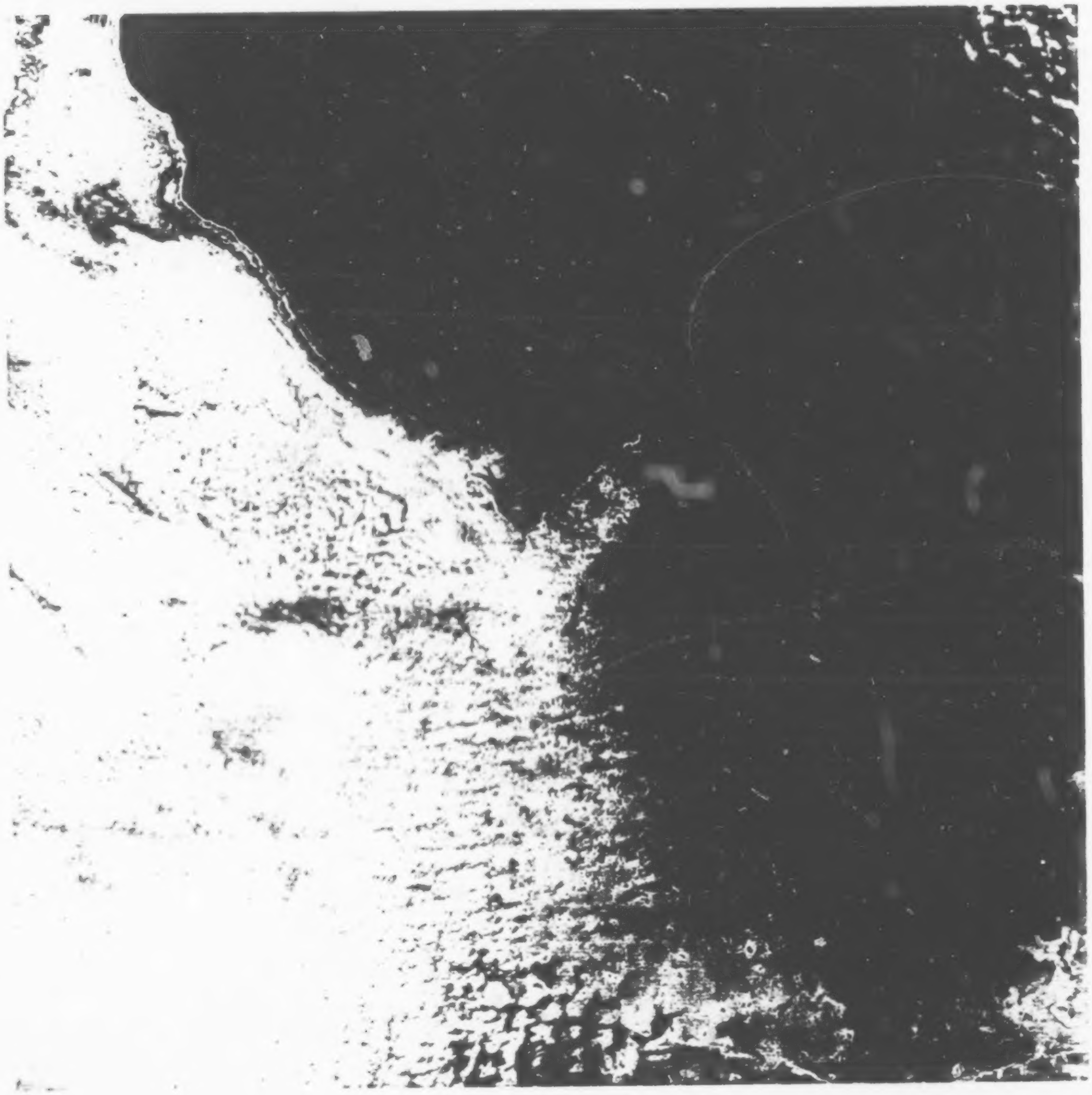
Lake Chad, West Africa



Scale 1 cm = 8 km

Landsat MSS
December 8, 1972

Lake Chad, which forms part of the borders of Cameroon, Chad, Niger, and Nigeria, has decreased considerably since the 1960's because of a prolonged drought. Historically, the area of the lake can fluctuate thousands of square kilometers between the dry season and the end of the rainy season. Reasons for these fluctuations are the relative shallowness of the lake, the diversion of water for irrigation, and climate. The lake covered approximately 26,000 square kilometers in the early 1960's. The December 8, 1972 image, shows the lake level lower than the mid-1960's level. After the extended drought of the 1970's and mid-1980's, the size of the lake

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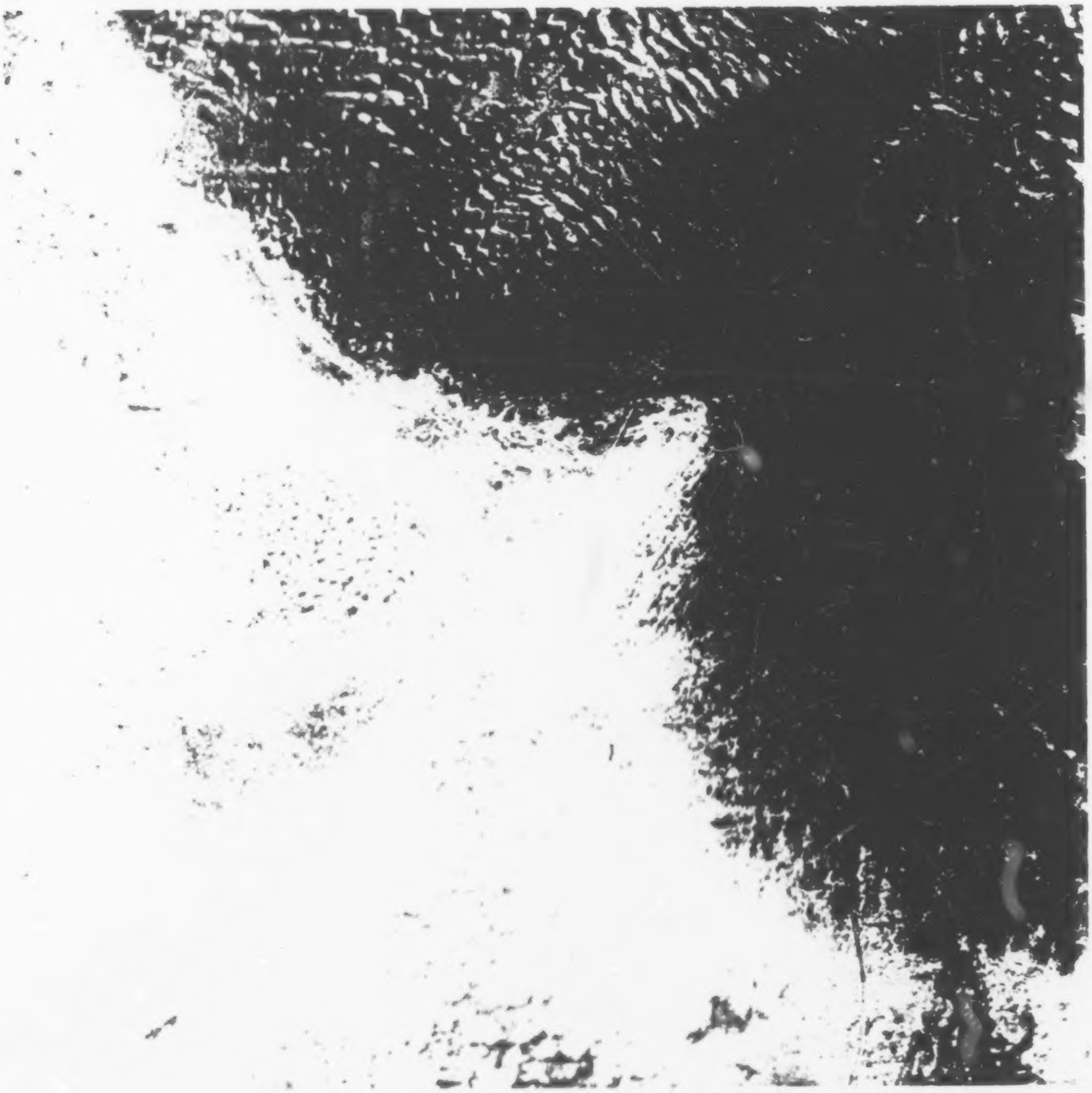

Scale 1 cm = 8 km

shrunk to less than 3000 square kilometers, the light blue area at right-center in the October 1987 image.

The Chari and Logone rivers, which contribute more than 80 percent of the total water supply for Lake Chad, were reduced to a trickle during the drought years. Many ancient dunes, long covered by the waters of the lake, are visible in the 1987 image. Note the old beach marks along the western side of the lake basin in 1987. Much of the former lake has been replaced by wetlands, indicating that the water table remains near the surface.

Landsat MSS
October 14, 1987

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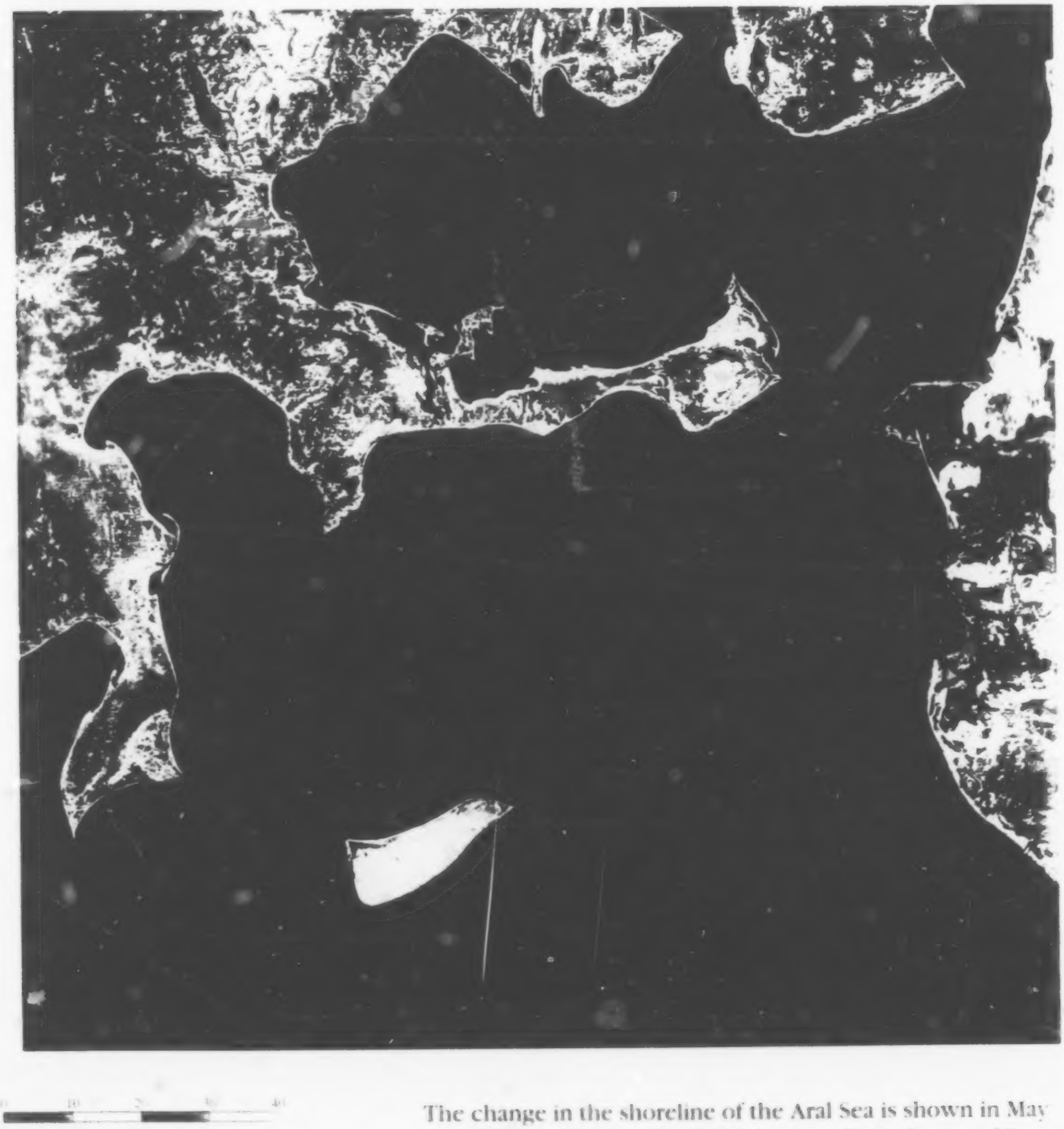
Aral Sea, Kazakhstan



Scale 1 cm = 9.5 km

Landsat MSS
May 29, 1973

The change in the shoreline of the Aral Sea is shown in May 29, 1973, and August 19, 1987, images. Over the past 30 years water has been diverted from the Amudar'ya and the Syr-Dar'ya rivers feeding the Aral to irrigate millions of acres of land for cotton and rice production in Central Asia. The diversion of water has caused a loss of over 60 percent of the lake's water since the 1960's. The lake has shrunk from over 65,000 square kilometers to less than half that size, exposing large areas of the lake bed. From 1973 to 1987 the Aral dropped from fourth to sixth among the world's largest lakes.

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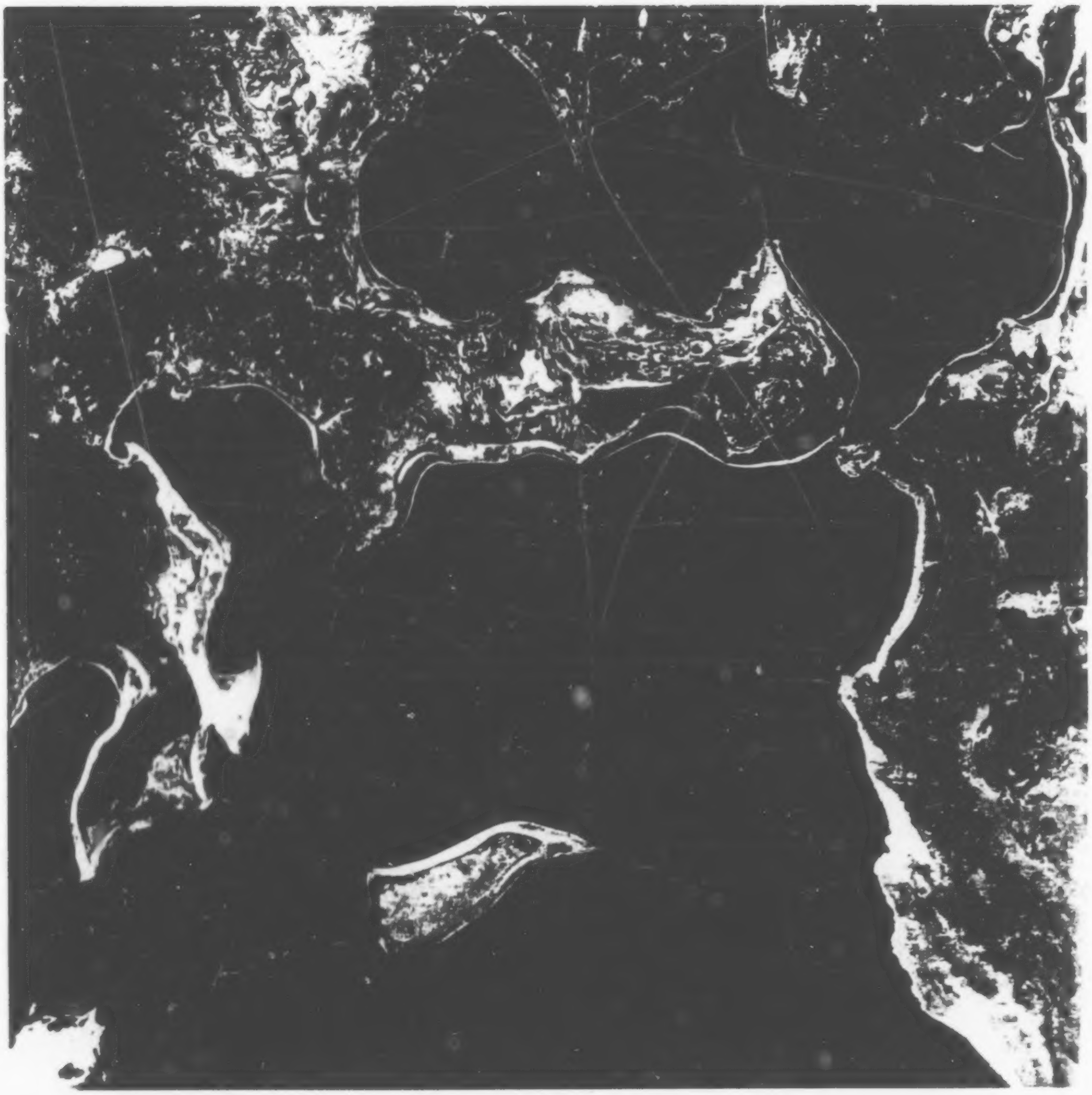

The environmental consequences of the shrinkage include doubling of the salt concentrations in the lake from 10 percent to more than 23 percent, which has contributed to the devastation of a once thriving fishery and a shift in the local climate. Summers are reportedly hotter and drier and the winters are colder and longer. Dust storms of salt particles and pesticide residues, originating from the exposed lake bed, create air pollution for hundreds of kilometers, resulting in widespread nutritional and respiratory ailments.

0 10 20 30 40

Scale 1 cm = 9.5 km

Landsat MSS
August 19, 1987

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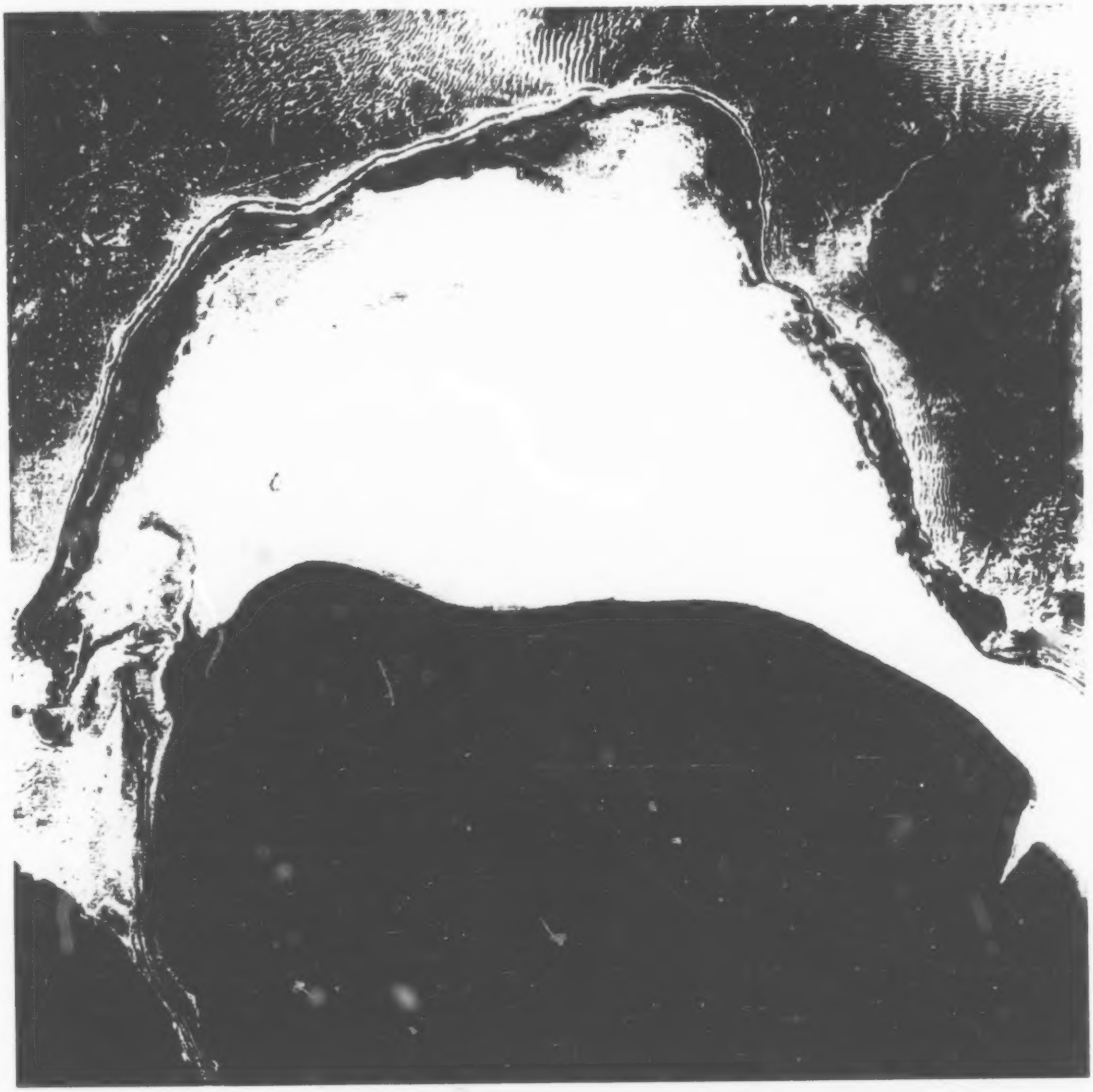
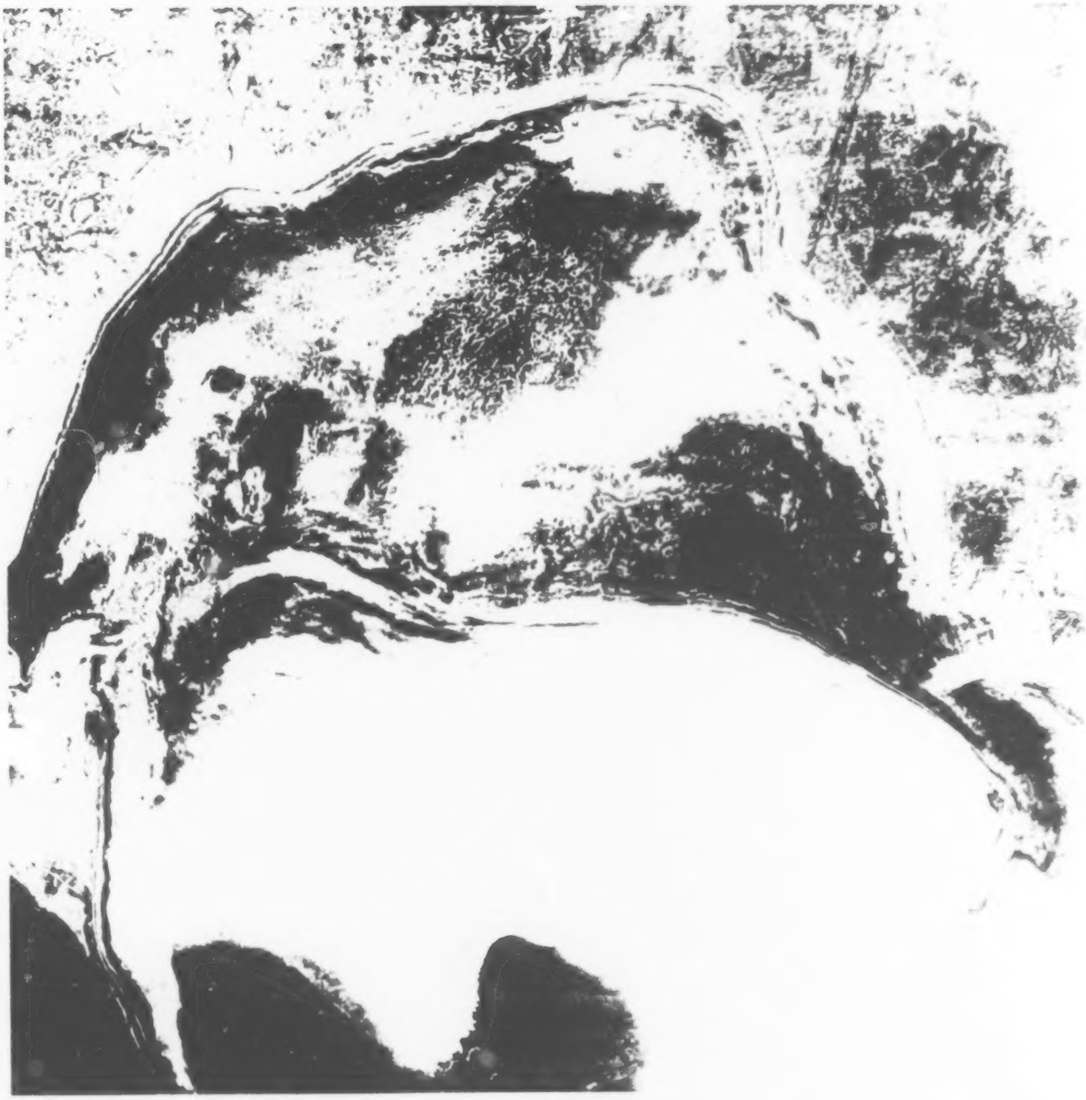
Kara-Bogaz-Gol, Caspian Sea,Turkmenistan



Scale 1 cm = 7.6 km

The depletion of water in the Kara-Bogaz-Gol (KBG), an inlet bay on the eastern side of the Caspian Sea, is shown. The KBG has been used as an evaporating basin for salts since the early 1920's. In March 1980 a dike was completed across the strait that connected the KBG with the Caspian Sea in an attempt to

Landsat MSS
December 4, 1972



help stabilize the water level of the Caspian Sea. The original estimate of 25 years for the water in the KBG to evaporate was optimistic. The impact was more dramatic, resulting in the complete evaporation of the water in the KBG by late 1983

Scale 1 cm = 7.6 km

Landsat MSS
September 25, 1987

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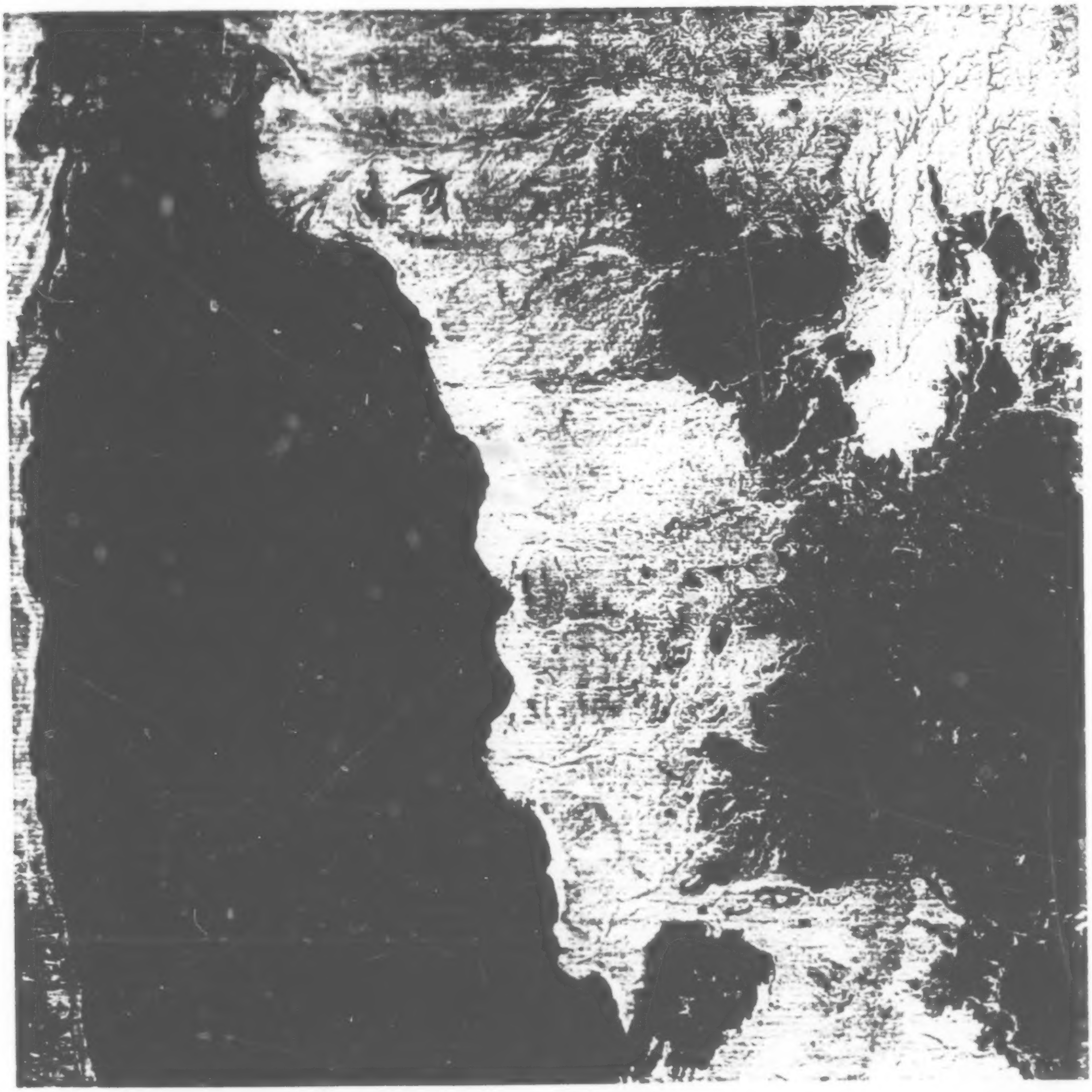
Lake Turkana, Kenya

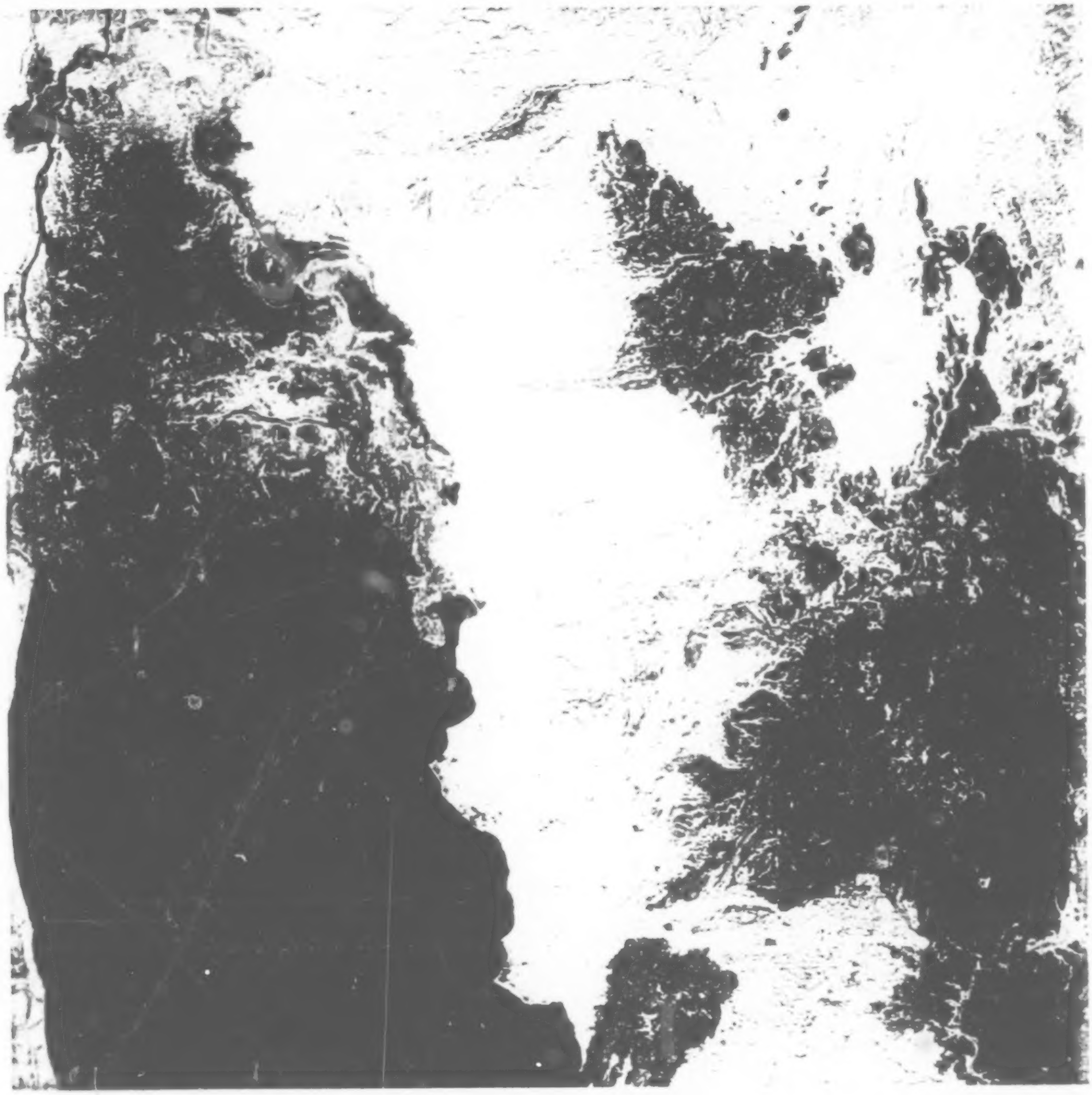


Scale 1 cm = 4.6 km

Landsat MSS
February 1, 1973

Lake Turkana, formerly Lake Rudolf, lies in the Rift Valley of East Africa. It is approximately 240 km long and 40 km wide with an average depth of about 35 meters. Images from February 1, 1973, and January 12, 1989, show changes on the delta of the Omo River on the north shores of Lake Turkana. The Omo River provides more than 80 percent of the fresh water to the lake, which has no outlet and lies in a very arid area of Africa.

The river delta increased by approximately 380 square kilometers between 1973 and 1989. This increase is largely



due to a precipitous drop in the water level, exposing the submerged portions of the delta. Aquatic vegetation has taken hold on the emerging delta. Prolonged drought, and the damming of three rivers for irrigation near the southern reaches of the lake have contributed to the lake's decline. Increasing water salinity threatens the lake's wildlife. The El Molo, Africa's smallest tribe with just over 200 members, live along the lake's southeastern shore. They fish and hunt Nile crocodiles along the lake shore.

Scale 1 cm = 4.6 km

Landsat MSS
January 12, 1989

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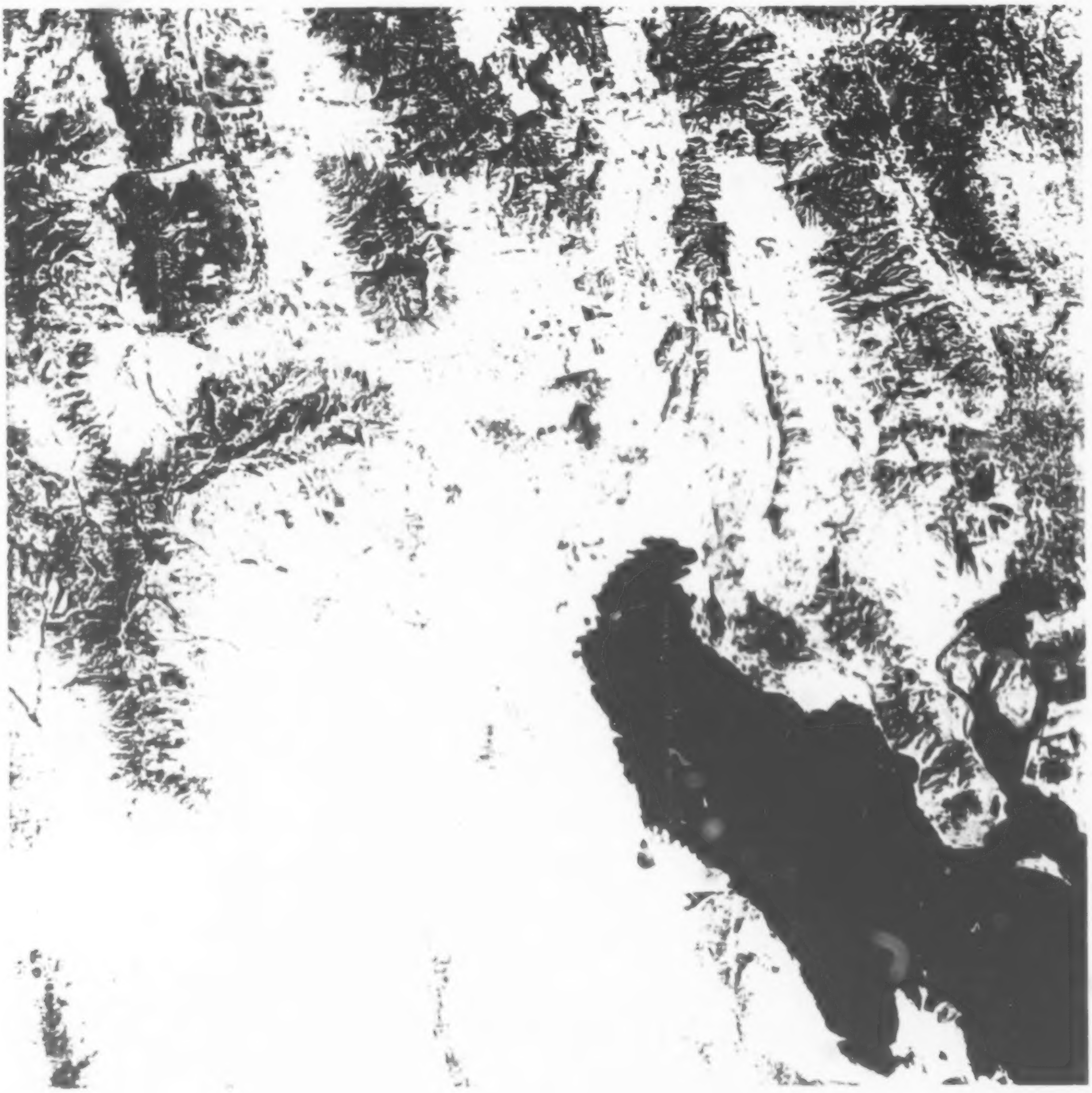
Great Salt Lake, Utah, USA



Scale 1 cm = 9.5 km

Landsat MSS
September 13, 1972

These images from 1972 and 1988 show the dramatic increase of the surface area of the Great Salt Lake in Utah. The rise in water level has increased the size of the lake to more than 5,900 square kilometers, from a low in 1963 of 2,300 square kilometers, and caused millions of dollars in damage by flooding highways, homes, wildlife refuges, and railways near the lake. In May 1986, the Utah legislature approved a project

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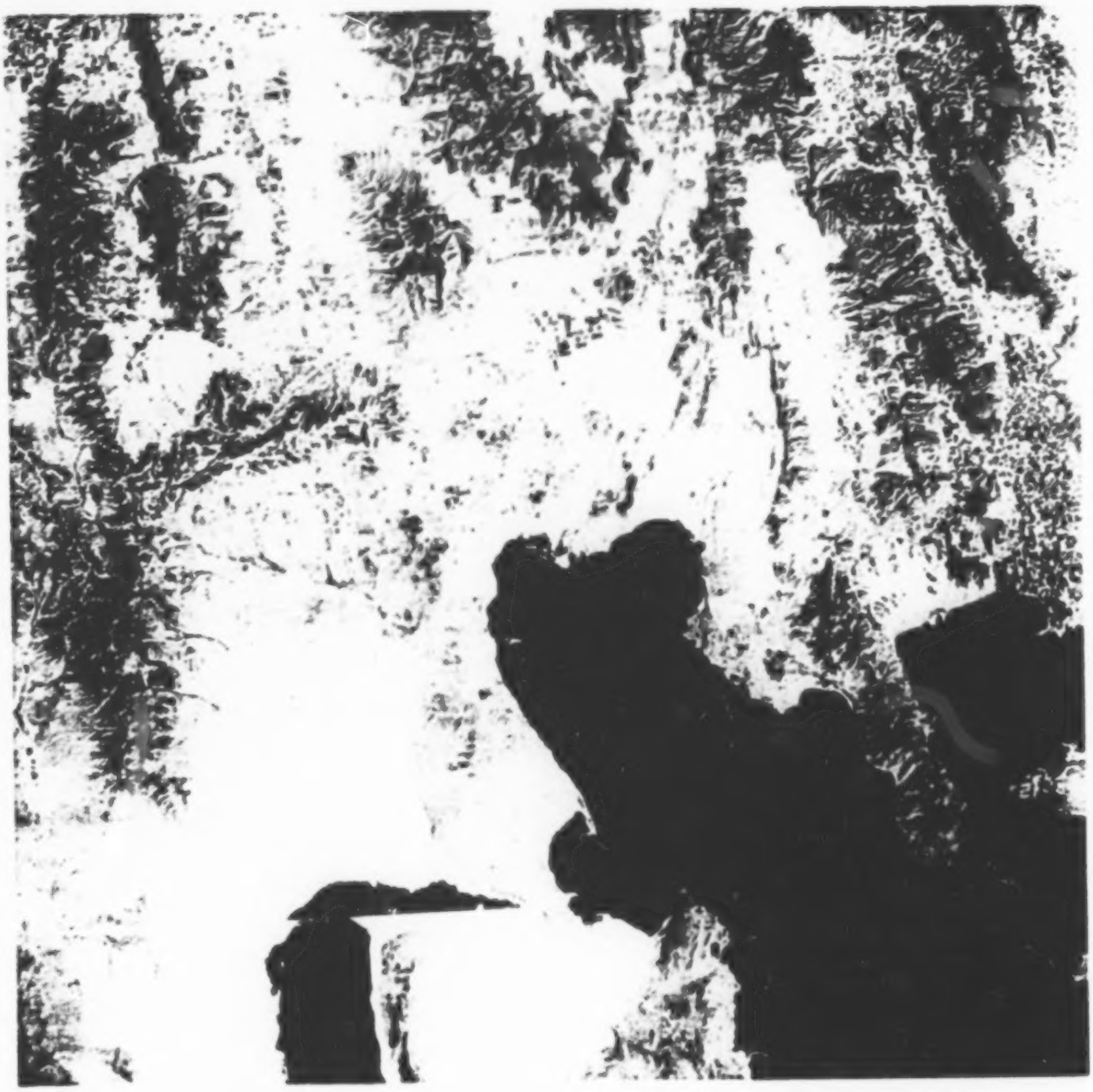

to pump excess water out of the Great Salt Lake onto a portion of the Bonneville salt flats west of the lake. This new water body, Newfoundland Evaporation Basin, which can be seen to the west of the Great Salt Lake in the 1988 image, was constructed to help control the level of the lake.

Scale 1 cm = 9.5 km

Landsat MSS
August 14, 1988

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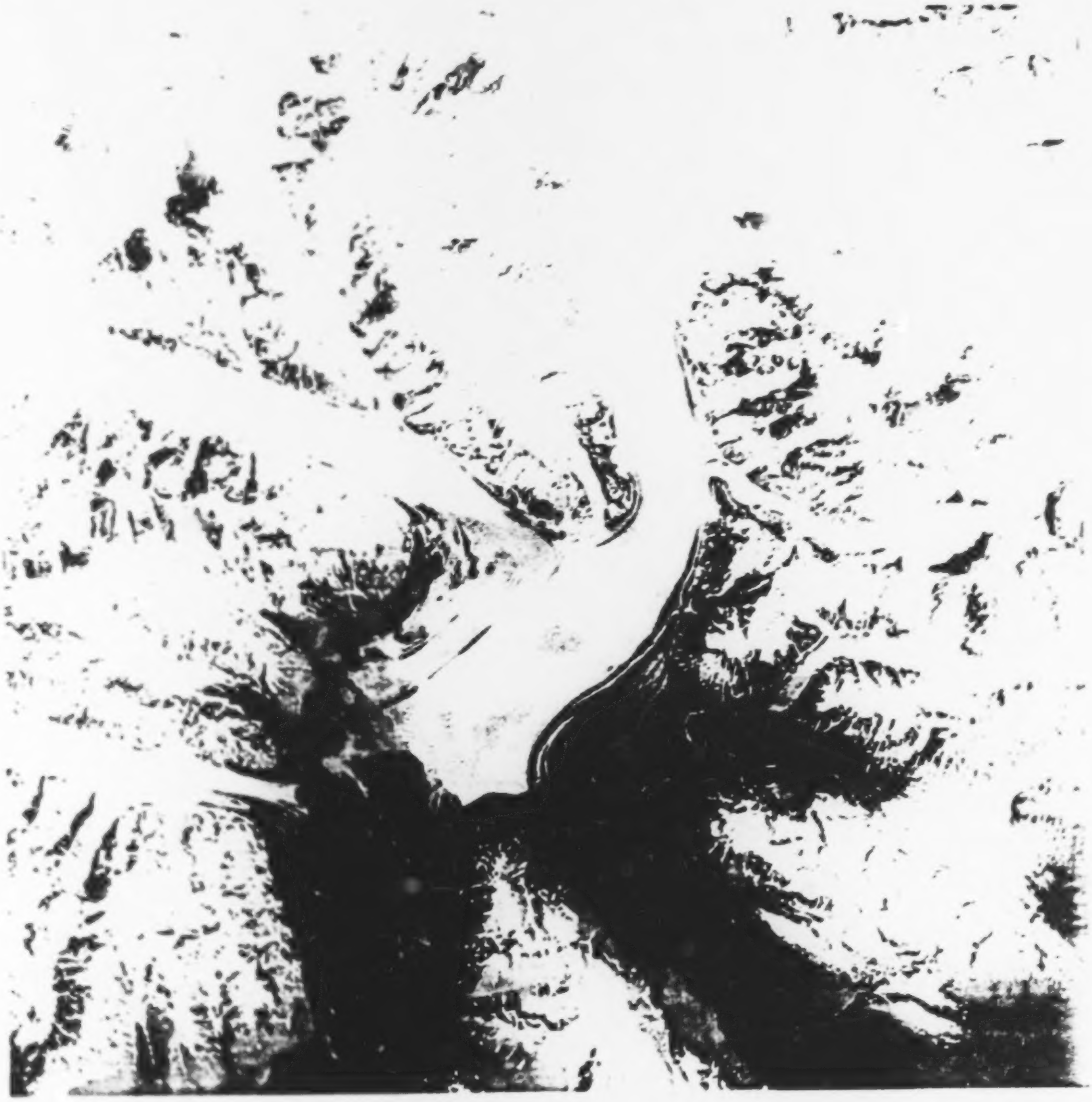
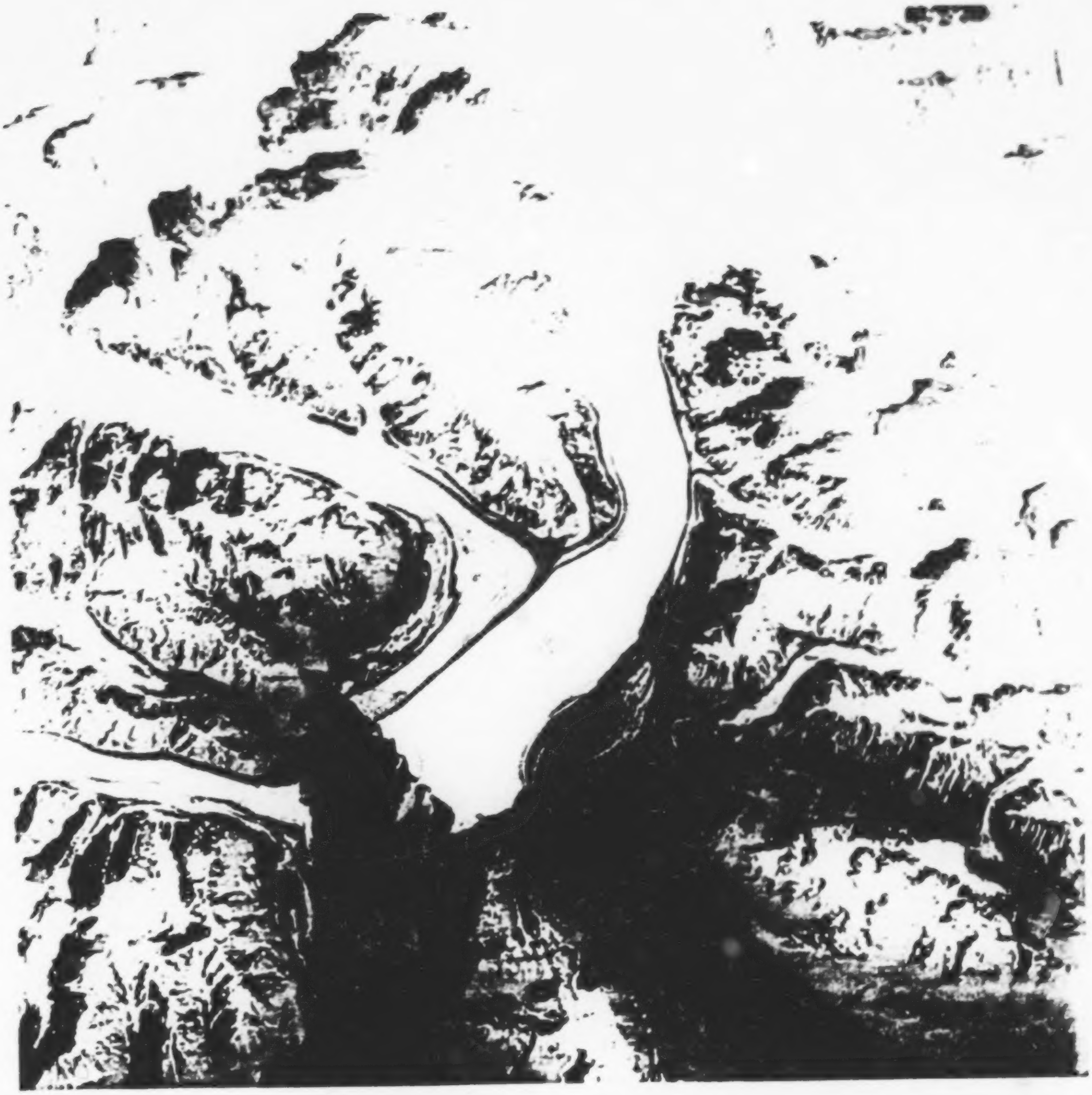
Hubbard Glacier, Alaska, USA



Scale 1 cm = 2.5 km

Landsat TM
August 7, 1985

In 1986 the Hubbard Glacier in the Wrangell-St. Elias National Park near Yakutat, Alaska, surged forward, blocking Russell Fiord. Russell Fiord, a saltwater fiord, began to rise from the runoff of the surrounding area and became known as "Russell Lake." The runoff reduced the salinity of the lake, endangering such sea life as seals and porpoises. Another concern over the



rising water level was the possibility of the fiord's draining southward into the Situk River and affecting the area's fishery. Before the ice dam broke on October 8, 1986, the water level of Russell Fiord rose more than 25 meters. These images show the area prior to the surge and while the fiord was blocked.

Scale 1 cm = 2.5 km

Landsat TM
September 11, 1986

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Access to Landsat Data

Information on the availability of Landsat and other types of images can be obtained from the U.S. Geological Survey's EROS Data Center.

Mail:	U.S. Geological Survey EROS Data Center Customer Services Sioux Falls, SD 57198
Telephone:	605-594-6151
FAX:	605-594-6589
E-mail:	custserv@edcserver1.cr.usgs.gov

Information on the availability of Landsat images can also be acquired through the Global Land Information System (GLIS). GLIS is an interactive computer system that provides information on land data sets to a wide range of users. It was developed for scientists seeking information and access to data pertaining to the Earth's land surface. GLIS contains references to regional, continental, and global data sets including land cover and land use, soils, topography, and data from aircraft and satellites. Direct access to GLIS is through wide-area networks and dial-up telecommunications interfaces:

- Text terminal access:
  - telnet glis.cr.usgs.gov
- Xwindows terminal access:
  - telnet xglis.cr.usgs.gov
- PC access dial-up modem:
  - Contact GLIS user assistance to request PC dial-up GLIS software or download the software over Internet from sunl.cr.usgs.gov/pub/software/pcglis

GLIS User Assistance:

Telephone:	1-800-252-GLIS (1-800-252-4547)
FAX:	605-594-6589
E-mail:	glis@glis.cr.usgs.gov

The Landsat images used in this booklet and their scene identification number and date of acquisition are listed below. The digital data are available on several types of media.

Description	Scene ID	Date
Glasgow, Missouri, USA	5025033009226810	September 24, 1992
	5025033009327010	September 27, 1993
Nile River Delta, Egypt	1190039007313090	May 10, 1973
	5177039008719990	July 18, 1987
Western Kansas, USA	1032034007222990	August 16, 1972
	5030034008822890	August 15, 1988

Description	Scene ID	Date
Northern Iran	2177035007719590 5165035008725990	July 14, 1977 September 16.1987
Central Saudi Arabia	1180042007236090 5167042008604690	December 25, 1972 February 15, 1986
Rondonia, Brazil	2249067007517090 5232067008621390 4232067009217410	June 19, 1975 August 1, 1986 June 22, 1992
Mount St. Helens, Washington, USA	1049028007325890 4046028008314290 5046028008824490	September 15.1973 May 22, 1983 August 31, 1988
Yellowstone Nat. Park, Wyoming, USA	5038029008820410 4038029008827610	July 22, 1988 October 2, 1988
Kuwait	4165040009024310 4165040009105410 5165040009131810	August 31, 1990 February 23, 1991 November 14, 1991
Dallas-Fort Worth, Texas, USA	1029037007407190 5027037008908190	March 12, 1974 March 22, 1989
South-Central Texas, USA	1029040007403590 5027040008807990	February 4, 1974 March 19, 1988
Lake Chad, West Africa	1199051007234390 5185051008728790	December 8, 1972 October 14, 1987
Aral Sea, Kazakhstan	1173028007314990 5161028008723190	May 29, 1973 August 19, 1987
KBG, Caspian Sea, Turkmenistan	1177031007233990 5164031008726890	December 4, 1972 September 25.1987
Lake Turkana, Kenya	1182057007303290 4169057008901290	February 1, 1973 January 12, 1989
Great Salt Lake, Utah, USA	1042031007225790 5039031008822790	September 13, 1972 August 14, 1988
Hubbard Glacier, Alaska, USA	5062018008521910 5062018008625410	August 7, 1985 September 11.1986

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